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FEASIBILITY PROTOTYPE CYCLOPS EYEPiece, WIDE ANGLE CYCLOPS EYEP--ETC(U)

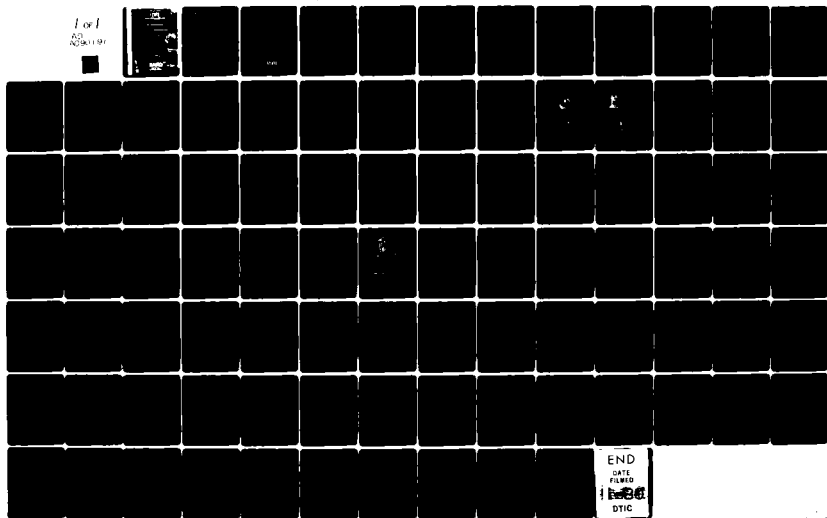
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DEPARTMENT OF THE ARMY  
ARMY NIGHT VISION AND ELECTRO-OPTICS LABORATORY  
FORT BELVOIR, VIRGINIA 22060

29 SEP 1980

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1. Reference Final Reports for the following contracts (Incl 1):

DAAG53-78-C-0114  
DAAG53-76-C-0114 (Mod P00001)  
DAAK70-76-C-0254  
DAAK70-77-C-0294  
Status December 1978

2. In accordance with DOD Directive 5200.20, the subject reports shall have an unlimited distribution.

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LOUIS M. CAMERON  
Acting Director  
Night Vision & Electro-Optics Laboratory

9 Final Report for Contracts

10

**Feasibility Prototype Cyclops Eyepiece**

Contract No. DAAG53-76-C-0114

**Wide Angle Cyclops Eyepieces**

Contract No. DAAG53-76-C-0114 (Mod P00001)

**Dual Channel and Cyclops Mini-Goggle Systems**

Contract DAAK70-76-C-0254

**Third Generation Systems .**

Contract DAAK70-77-C-0294

December 1978

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Department of the Army  
United States Army Electronic Command  
Night Vision Laboratory  
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This report documents the work done under Government contract number's DAAG53-76-C-0114, DAAK70-76-C-0254, and DAAK70-77-0294, as issued by Night Vision Laboratories of Fort Belvoir, Virginia. All of the contracts were concerned with the design and fabrication of optical systems as part of Night Vision Laboratory's low cost night vision goggle development.

A major portion of this work was the development of an innovative eyepiece system which permits the use of a single image intensifier tube per night vision goggle. This eyepiece, referred to as a cyclops eyepiece, was to provide two-eye viewing of a single tube output. The development goals were to obtain operation performance equivalent to the standard dual channel systems currently utilized by the United States Army personnel. Investigations were carried from an initial 18mm, 40° field of view feasibility model through a 12mm format system, wide angle systems in 18mm and 25mm formats to a final 18mm format 40° field of view cyclops eyepiece reflecting all of the experience gained.

Other areas examined under these contracts, and discussed herein, were 12mm dual channel goggles, and high performance objective lens for second and third generation intensifier tubes.

A comprehensive set of conclusions based upon all of the work efforts is included at the end of the report, accompanied by recommendations for future studies.

This contract work was designed to investigate the feasibility of a 40° field eyepiece system providing two-eye viewing of a single 18mm format tube output. Baird Corporation worked toward providing an eyepiece which:

- 1) is lightweight, small and comfortable,
- 2) provides strain-free viewing for long periods,
- 3) has sufficient resolution to permit viewing all the central image information content of the tube, and
- 4) offers potentially low production cost.

At the beginning of the effort, Baird evaluated several techniques, and determined that the best approach was to collimate the tube output and to share the collimated light between two de-centered eyechannels, each channel consisting of a reimaging lens and a focusing eyepiece. Figure 2-1 is a block diagram of the technique. Note that the reimaging lens modules present an image of the tube output to the focusing eyepiece modules, thus the collimator and reimaging modules perform a relay function.

This method has several advantages over other techniques; these include:

- 1) high transmission (70% to 75% possible),
- 2) no image inversion necessary in tube, and
- 3) 100% overlap of the field viewed by each eye.

A beam splitter approach would have an estimated maximum transmission to each eye of 40%. The shared field system loss does not split the energy density between the two eyechannels, but rather, shares the collimated light at the collimator output, thus maintaining the energy per unit solid angle.



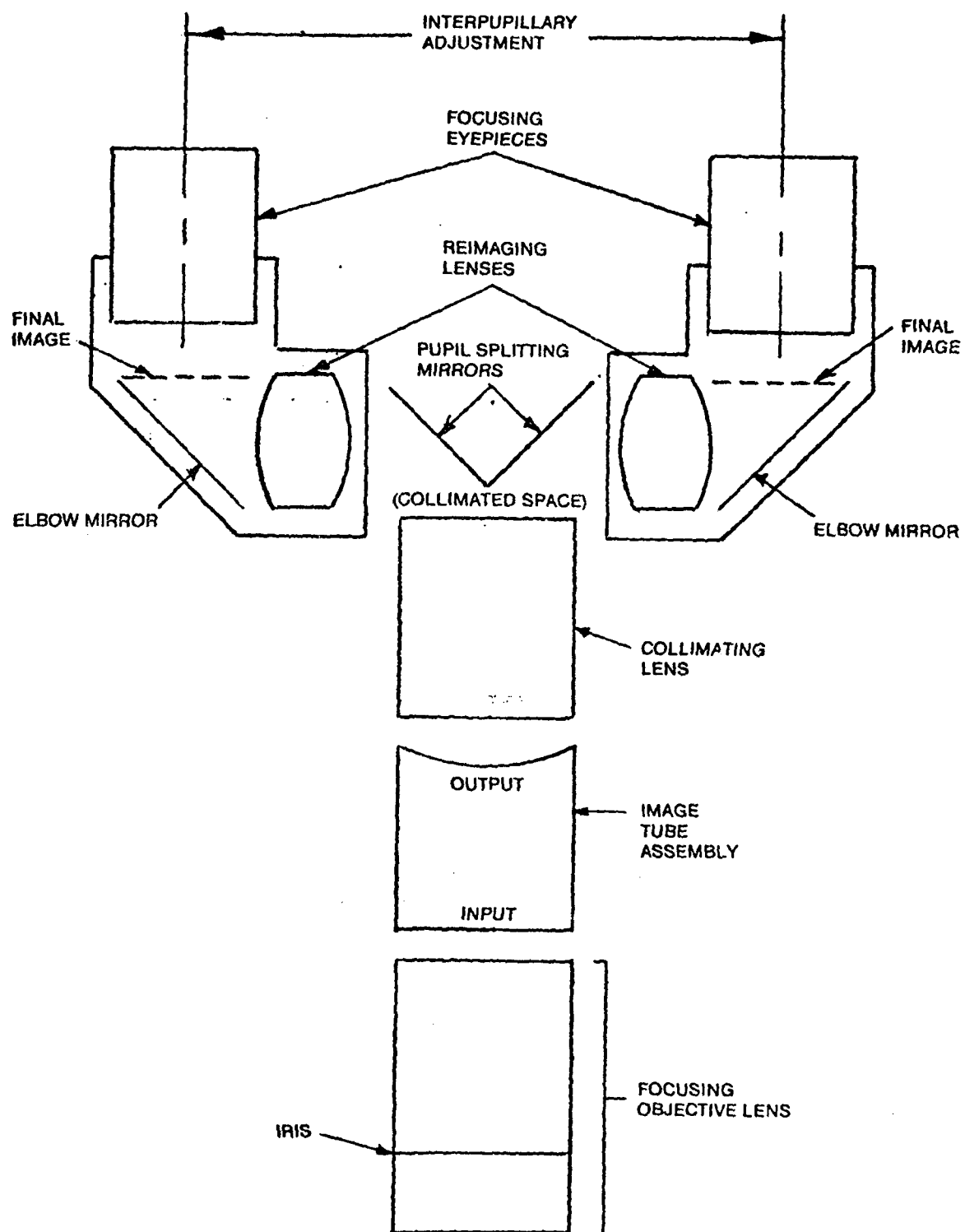


Figure 2-1. Basic Component Block Diagram

Because the system has one reimaging step, a noninverting tube assembly is required. This is advantageous over a twister inverting tube because the tube: 1) is smaller and lighter, 2) is less costly, 3) has inherently better transmission (brightness gain), and 4) has maximum possible numerical aperture. The first three advantages are obvious; the fourth is very important for the single channel approach, since the output of the tube will be used as the object to a fast collimating lens, and a restricted NA would reduce the exit pupil size.

The overlap of 100% is a desirable feature as it eliminates "blinder" effects. "Blinder" effects result when each eye see but a portion of the total field. A case of this is when the right eye can see the left half of the field, but not the right. This amounts to having "blindners" mounted to the side of one's head. Though overlaps of up to 25% are used in biocular eyepiece systems and have proven adequate, since the 100% is possible and it duplicates the standard AN/PVS-5 situation, it is desirable to strive for this condition.

## 2.1 OPTICAL DESIGN

Early discussions with Night Vision Laboratory project personnel led to the specification of the image tube to be coupled to the prototype eyepiece, and the realization that correction of field curvature was going to be a serious problem. The tube specified had a non-twisting fiber optic faceplate as required by this design, but with a shallow curvature of 32mm radius. The reimaging lens/focusing eyepiece combination of each eyechannel

is really two back-to-back eyepieces. This type of combination results in a cancellation of lateral color, coma, and distortion if the two components are nearly symmetric. However, spherical aberrations, axial color, astigmatism, and field curvature are cumulative. Because the number of elements in the eyechannel must be limited for weight and size reasons, only spherical and axial color can be fully corrected in both the reimaging lens and focusing eyepiece with lateral color, coma, and distortion held low enough to prevent visible problems when the focusing eyepiece is adjusted out of the symmetric state. The remaining field curvature and astigmatism must then be fully counter-balanced by the collimator design when the curvature of the tube output faceplate provides insufficient compensation. Appendix A includes a drawing of the specified tube interface.

The first design passes indicated that, with a minimum number of elements in both the reimaging lens and focusing eyepiece, the field curvature could not be designed to a level low enough to allow compensation by the collimator. To provide additional correction, it was determined that field flattening elements, with no power, had to be inserted in both the focusing eyepiece and reimaging lens, as close as possible to the image between them. Physical interference conditions, which arise when attempting to achieve the desired 55 to 72mm interpupillary adjustment, and +2 to -6 diopter eyepiece focus, do not permit two distinct elements, one in each component of the eyechannel, to be used. A hemispherical dome concentric with the intermediate image was, therefore, inserted into the system and the elbow

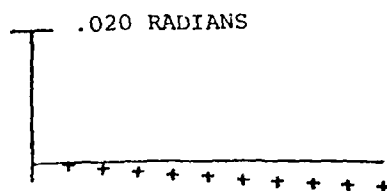
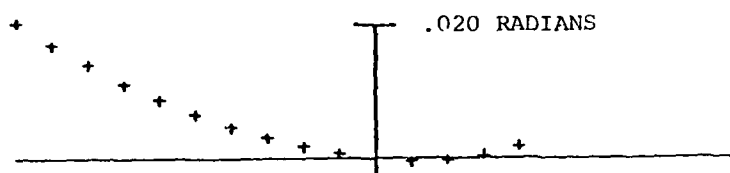
mirror made slightly negative. This provides the same effect as two distinct miniscus elements.

The final eyepiece design has a reimaging lens module length requiring each eyechannel to be folded in a "Z" in order to attain the required interpupillary range of 58 to 72mm. The system is folded, such that, the eyechannel has an included angle of  $70^{\circ}$  between the focusing eyepiece and reimaging lens axes.

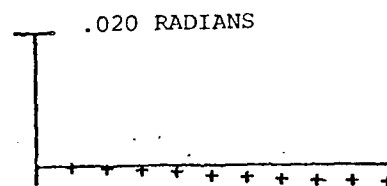
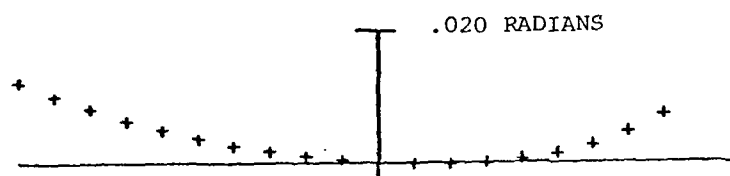
Figures 2-2 through 2-4 are the aberration fan plots of the cyclops eyepiece components. Figure 2-2 shows the characteristic curves of both the focusing eyepiece and the reimaging module, which have the same lens elements. Figure 2-3 demonstrates that the coma is not present in the back-to-back configuration of the eyechannel and the slopes of the sagittal fans are approximately doubled. This confirms the cancellation of coma and accumulation of field curvature as discussed earlier. These aberrations also includes the effects of the negative mirror element in the intermediate image plane, and the  $70^{\circ}$  included angle. In actuality, an additional mirror exists in the system, hence, the real curves are the mirror image of those shown. The collimator curves of Figure 2-4 present those aberrations as seen when looking into the collimator at the tube output.

The analysis of the system aberrations as a function of the individual component aberrations is complex. The decentering of the eyechannels eliminates axial symmetry, and therefore, the coupling of the eyechannel aberrations with the collimator aberrations result in system aberrations which are different for the left and right semicircles of the viewed field. During design,

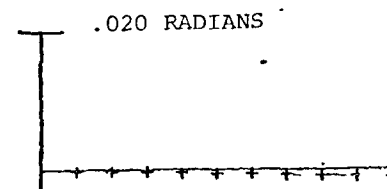
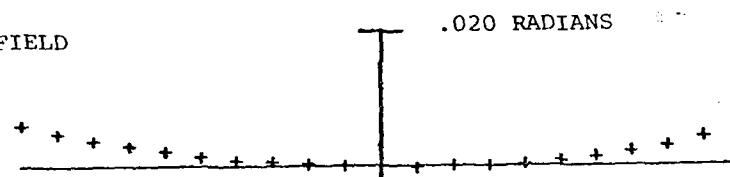
100% FIELD



70% FIELD

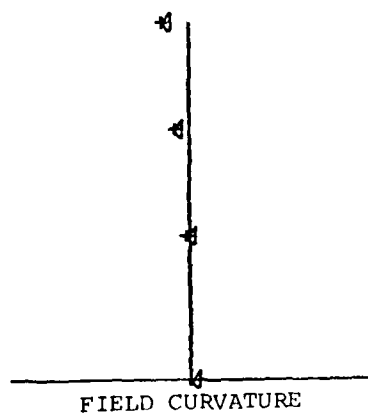


40% FIELD



TANGENTIAL FANS

SAGITTAL FANS



FIELD CURVATURE

ON-AXIS FANS

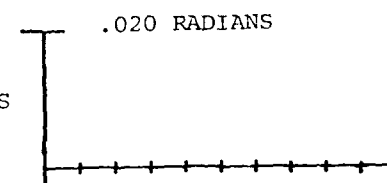


Figure 2-2 Aberration Fan Plots - Individual Reimaging Lens and Focusing Eyepiece Assemblies

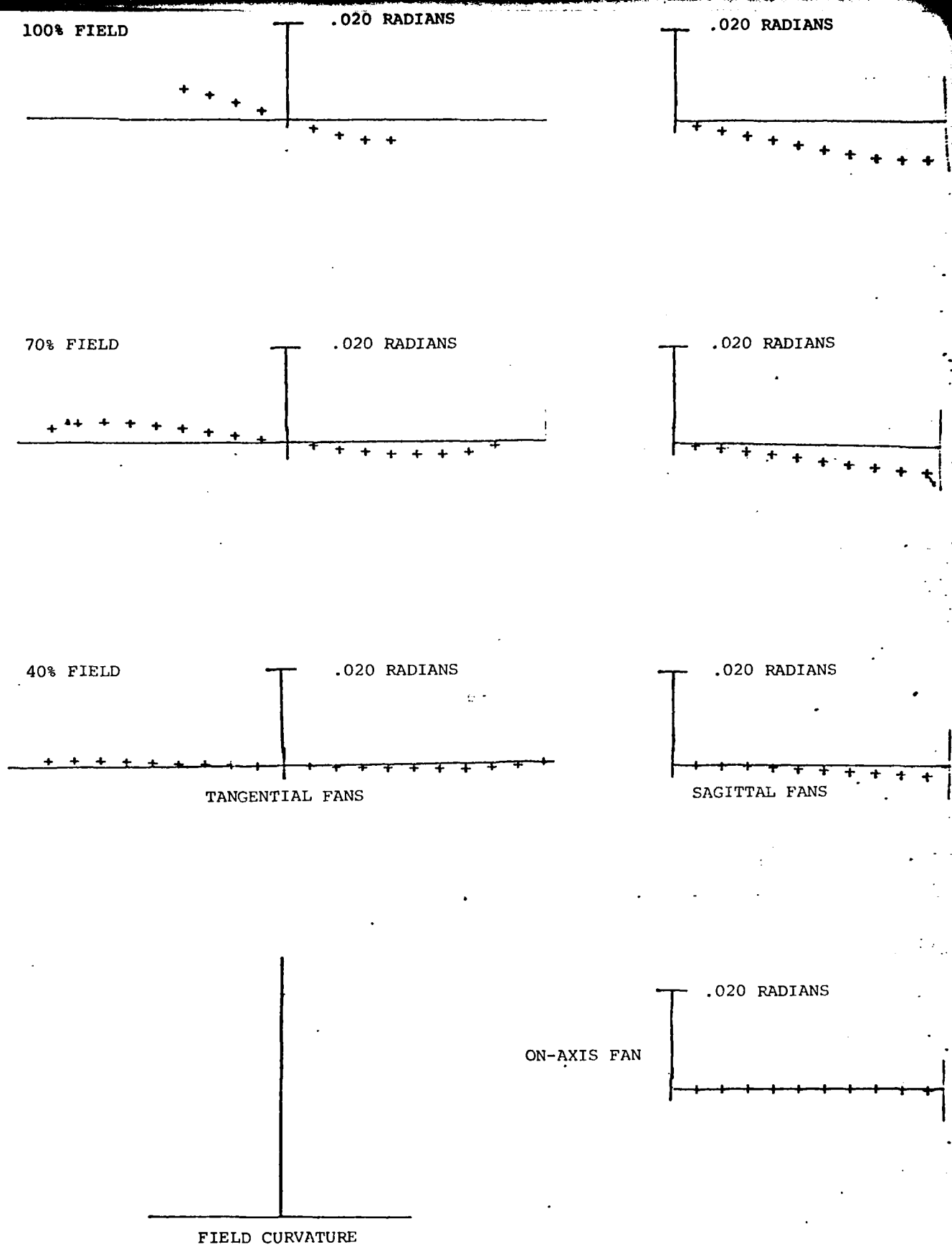


Figure 2-3 Aberration Fan Plots - 18mm Format Feasibility Model  
Cyclops Eyechannel

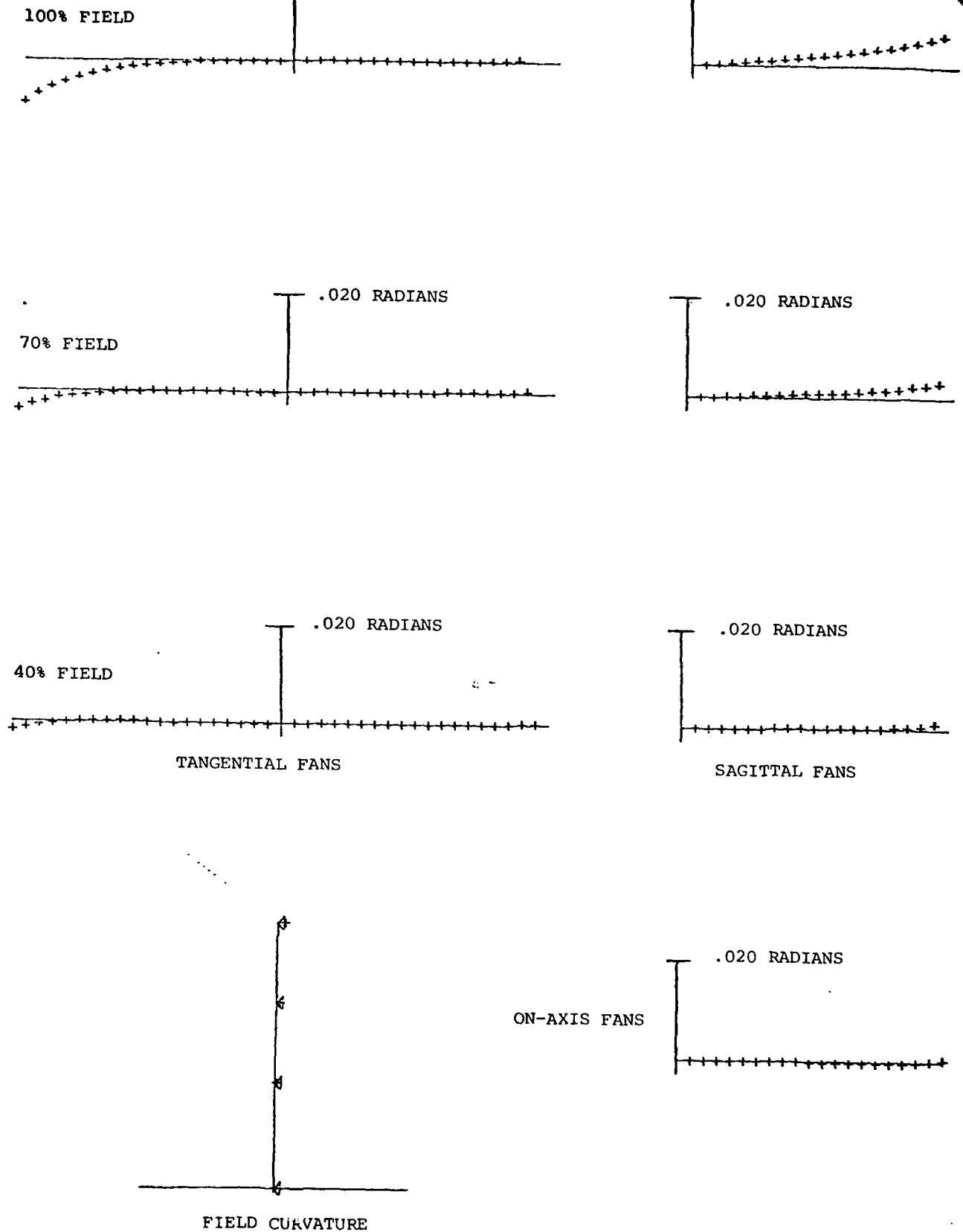


Figure 2-4 Aberration Fan Plots - 18mm Format Feasibility Model  
Cyclops Collimator

a great many exact rays and fan traces must be run through the system to confirm the proper overall performance. The full details of such an analysis are too complex to reiterate in this report, and therefore, a more comprehensive overview is presented.

Examination of the eyechannel and collimator curves of Figures 2-3 and 2-4 (Note that full aperture of the collimator plots is twice the eyechannel aperture and that in practice, the eyechannel is decentered in the collimator aperture), shows that the sagittal field components are matched. The tangential field curvature of the collimator is much less over-corrected resulting in residual astigmatism when coupled to the eyechannel. The amount of resultant blur is controlled by vignetting the tangential pupil in the eyechannel, giving a cat's eye off-axis pupil. This type of system is used primarily because decentering the eyechannel pupil in the collimator pupil requires the tangential fan to be relatively flat so that minimum aberrations occur when viewing the periphery of the field. Different lens zones of the collimator are used when looking left, right, and up and down, and therefore, different aberration balances occur. Flattening the collimator tangential field holds these effects to a minimum.

Table 2-5 lists component and system descriptions as specified by the contract with the Baird design results.

## 2.2 MECHANICAL DESIGN

The major influencing factor and center of mechanical trade-off analysis was the interpupillary adjustment mechanism. A two-point hinge was employed (Figure 2-6). The size and shape of the mount necessary for establishing the two-hinge points was limited to control physical interference with normal facial structures.



	<u>Contract Specification</u>	<u>Baird Design</u>
<u>Focusing Eyepiece</u>		
Focal Length	N.S.*	19.65mm
Field of View	N.S.	41°
Optical Backfocus	N.S.	8.29mm
<u>Reimaging Lens</u>		
Focal Length	N.S.	19.65mm
Field of View	N.S.	41°
Optical Backfocus	N.S.	8.29mm
<u>Collimating Lens</u>		
Focal Length	N.S.	26.00mm
Field of View	N.S.	40.7°
Aperture Diameter	N.S.	20mm
Optical Backfocus	N.S.	1.80mm
<u>Total Eyepiece System</u>		
Format	18mm diameter on 32mm radius of curvature	18mm diameter on 32mm radius of curvature
Focal Length	27.0 + 1mm	26.0mm
Field of View	N.S.	40.7°
Distortion	N.S.	-8% nominal
Pupil Diameter	N.S.	9.8mm
Eye Relief	N.S.	17.8mm
Field Overlap	100%	100%
Interpupillary Range	55 to 72mm (desirable)	55 to 72mm
Eyepiece Focus Range	+2 to -6 diopters (desirable)	+2 to -6 diopters
<u>Collimation</u>		
Convergence	N.S.	+ 1° (goal)
Dipvergence	N.S.	+ .5° (goal)

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\* Not Specified

Table 2-5 Specifications and Design Results - 18mm Format, 40° Field  
Feasibility Model Cyclops Eyepiece

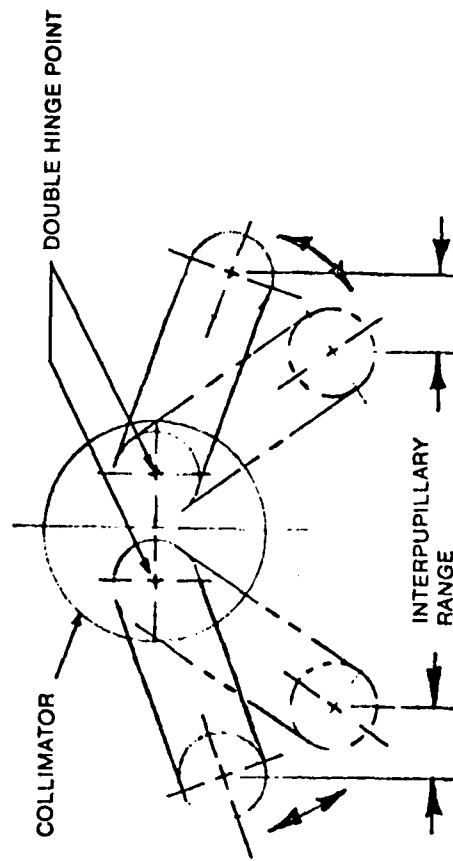


Figure 2-6 Double Hinge Interpupillary Adjustment Mechanism

Operation of the interpupillary mechanism was designed like that of a folding binocular where the operator presses at the center of rotation, thus lifting the center and pulling in the two eye-channels. To make the two eyepieces move together, a trace mechanism was designed into the front section (objective side) of the eyepiece housing. This holds the eyepieces in a constant plane relative to the facemask. An upward motion of the collimator, tube, and objective lens results as the interpupillary setting is reduced. Figures 2-7 and 2-8 shows the mechanics of the system.

The apertures of the collimator output and the eye-channel inputs, and the rotation necessary to cover the desired 55 to 72mm interpupillary range result in an unsealable void where the two eyechannels fold together. In that, the purpose of this work effort was a demonstration of the feasibility of a cyclops eyepiece system in a package suitable for headwear; this void was left rather than designing a large, complex sealing structure.

Field curvature correction requires a negative element close to the intensifier tube output in the collimator (Figure 2-7). The inner diameter of the aperture of the output of the image intensifier specified (Appendix A), was sufficient to insert the lens barrel length needed to support this element. In the interest of demonstrating the optical quality possible at this feasibility model level, the negative element was mounted separately to the image intensifier output faceplate with the remainder of the system mounted to the specified flange fixture.

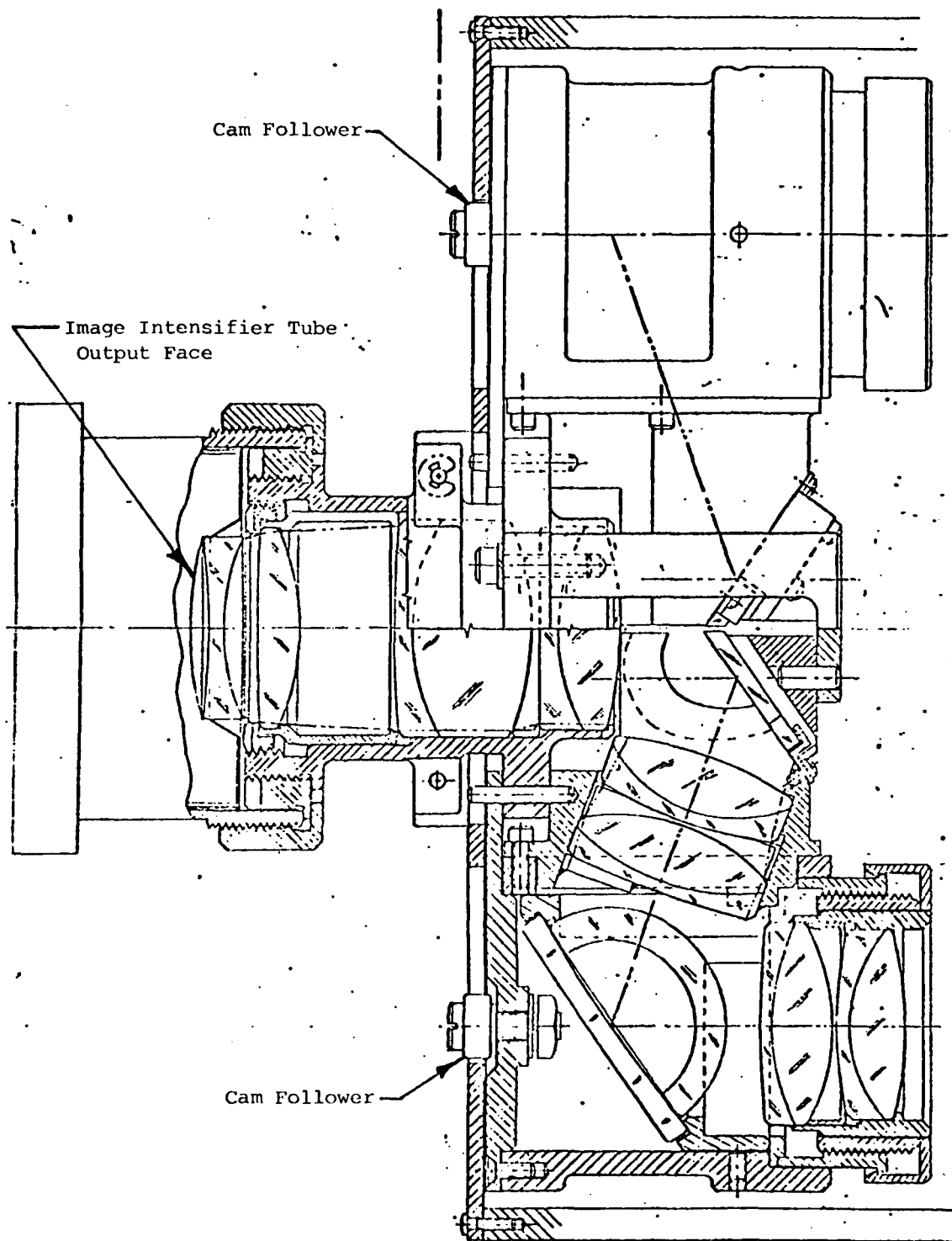


Figure 2-7 Mechanical Layout - 18mm Format Feasibility Model  
Cyclops Eyepiece

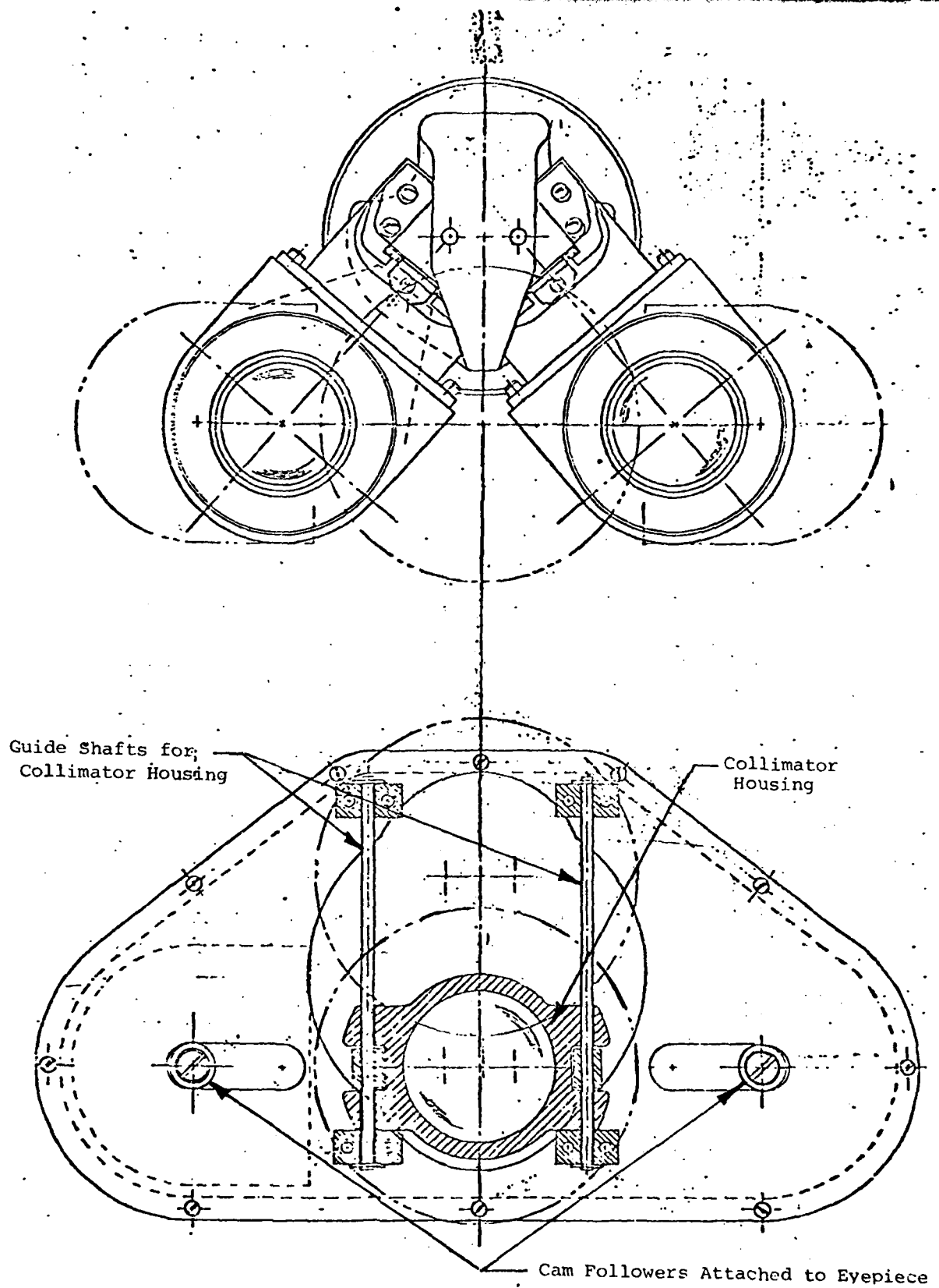


Figure 2-8 •Interpupillary Mechanics - 18mm Format Feasibility Model  
Cyclops Eyepiece

## 2.4

## RESULTS

Figure 2-9 shows the final eyepiece assembly.

Figures 2-10 and 2-11 show the eyepiece coupled to an NVL supplied AN/PVS-5 objective lens/fiber optic tube approximator combination and the full system installed in a standard goggle mask.

After each of the eyechannels had been aligned independently, they were coupled to the collimator. The initial coupling presented images which were plagued with collimation error, magnification, and aberrations. All of the above were directly attributable to: 1) collimator defocusing, 2) hinge mount problems, and 3) accumulation of residual alignment errors in each channel. The hinge problems were improved by reworking the parts, and the eyechannels were rechecked for alignment. The collimator focus error was examined more closely.



Figure 2-9. Feasibility Prototype 40° Field of View, 18mm Format Cyclops Eyepiece

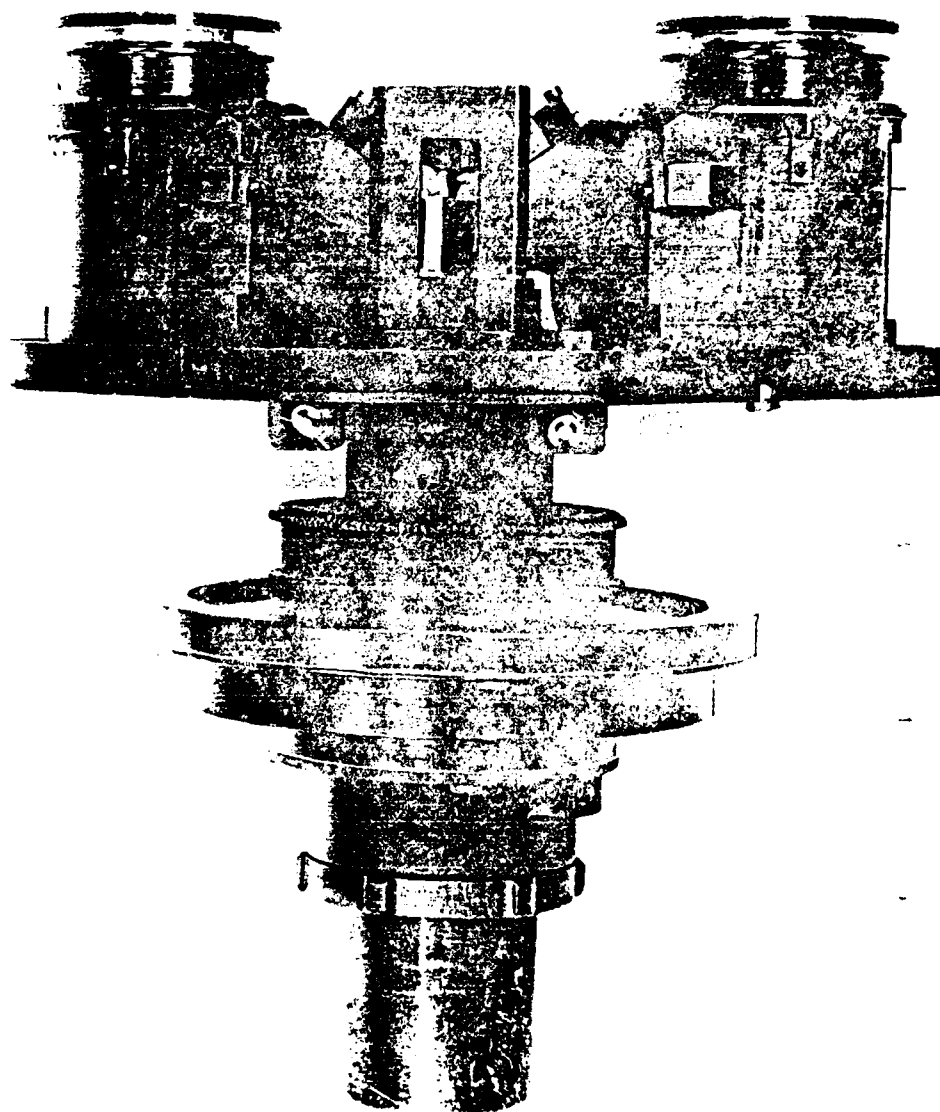


Figure 2-10. Feasibility Cyclops Eyepiece with NVL Supplied AN/PVS-5 Objective Lens and Tube Housing



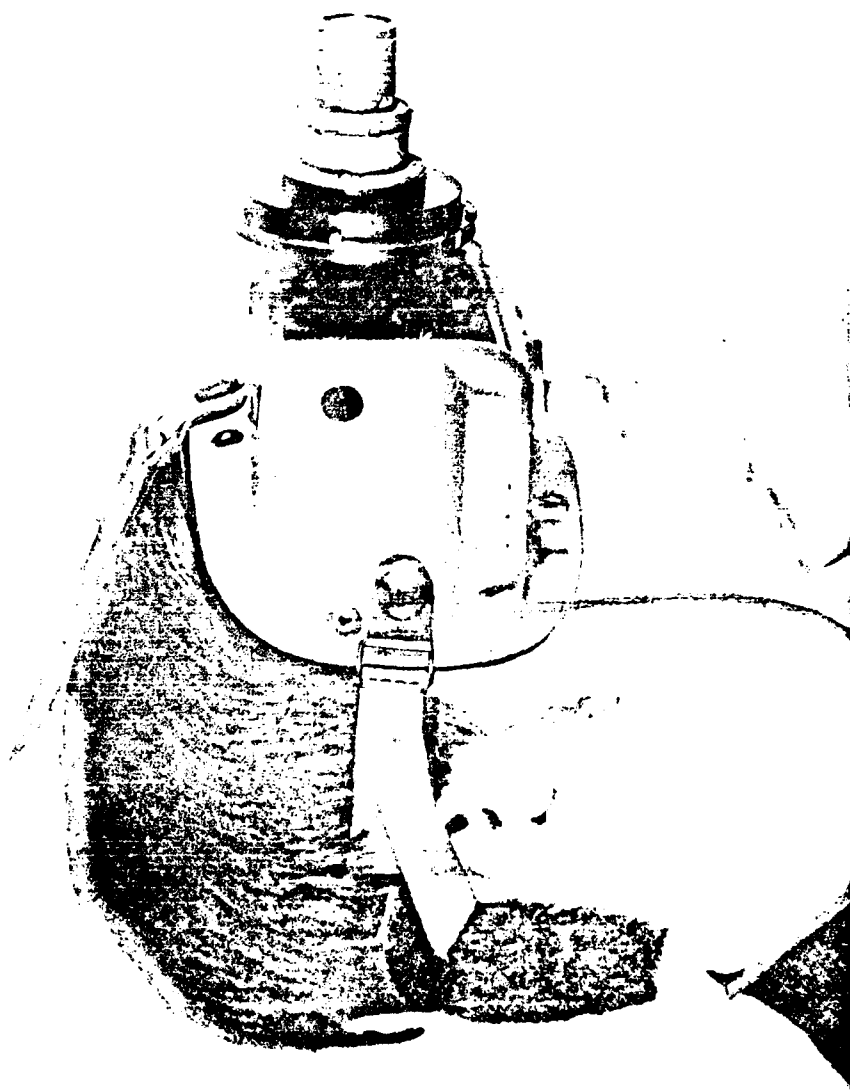


Figure 2-11. Feasibility Cyclops Eyepiece with NVL Supplied Tube Housing and Objective Lens  
Mounted in a Standard Facemask

The major goal of this program was to design and build 40° field of view lightweight small format goggles with potentially low production cost in both dual channel and cyclops configuration.

The dual channel system consists of two distinct monocular channels coupled into a binocular type of configuration; each channel having a fast objective lens, diode or double diode inverting image intensifier, and a magnifier eyepiece. The cyclops system has a single non-inverting image intensifier tube of double diode, plus diode or double diode construction, a single fast objective lens, and a cyclops eyepiece with interpupillary adjustment and eyepiece focus incorporated. Two of each type of system were delivered.

Appendix A includes drawings of the tubes specified. Both the input and output faceplates of the tubes are curved surfaces. This feature was incorporated to maintain high optical quality with short focal lengths in compact assemblies.

Difficulties encountered in building the feasibility model 18mm format cyclops inspired the development of a new approach to interpupillary adjustment for the cyclops eyepiece. Instead of rotating the eyechannels, and therefore, pushing the objective lens, tube, and collimator up which might lead to interferences with

military headgear, the system was designed to trombone the eyepieces simultaneously. This is possible for shorter focal length modules. Without complex prism and reflecting elements, this approach must work in a right angle configuration. Further comments will be included in the next sections.

### 3.1 OPTICAL DESIGN

#### 3.1.1 12mm Format Objective Lens

A single objective lens was designed for use with both the dual channel magnifier eyepiece and the cyclops eyepiece. By making maximum use of the 17.5mm radius of curvature on the fiber optic input, the design goal of  $f/1.0$  in six elements was achieved. Table 3-1 lists the contract specifications for the objective lens, and Baird's design results. All of the design goals hoped for were attained, with the exception of length. The  $42.6^\circ$  field of view, exceptional  $f/\text{no.}$  of  $f/.988$  and high resolution out-weighed the extra 4mm of length. Figure 3-2 shows aberration fan plots for the final design, with plots of the MTF for  $0^\circ$  and  $14^\circ$  off-axis included in Figures 3-3 and 3-4. These figures show the high resolution capability of this design both on and off axis, with the off-axis resolution maintained without need of significant vignetting (approximately 60% relative illuminance at full field).

#### 3.1.2 12mm Format Dual Channel

Table 3-5 lists the contract specifications with the final design results. The eyepiece, consisting of a doublet and two singlets, is fully corrected over the central 7mm pupil, with adequate correction over a 15mm diameter to prevent significant

	Contract Specification	Baird Design (theoretical)
Format	12mm, radius of curvature $\geq$ 17.5mm	12mm, radius of curvature = 17.5mm
Field of View	40° minimum	42.6° for 12mm
Effective Focal Length	17mm	16.9mm
Distortion	10% barrel	9% barrel
Transmission	94% for S25 Photocathode	94.1% (theoretical)
f/no.	f/1.0	f/.988
Weight	30 grams	22 grams without housing
Length	29mm	33.9mm
Outer Diameter	20mm	less than 20mm without housing
MTF Full Aperture On-axis		
20 lp/mm	80%	(See Figures 3-5 and 3-6)
40 lp/mm	65%	
Focus Range	1 foot $\rightarrow$ infinity	1 foot $\rightarrow$ infinity
Optical Backfocus (infinity)	N.S.*	1.70mm

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\* Not Specified

Table 3-1. Specifications and Design Results - 12mm Format  
Objective Lens

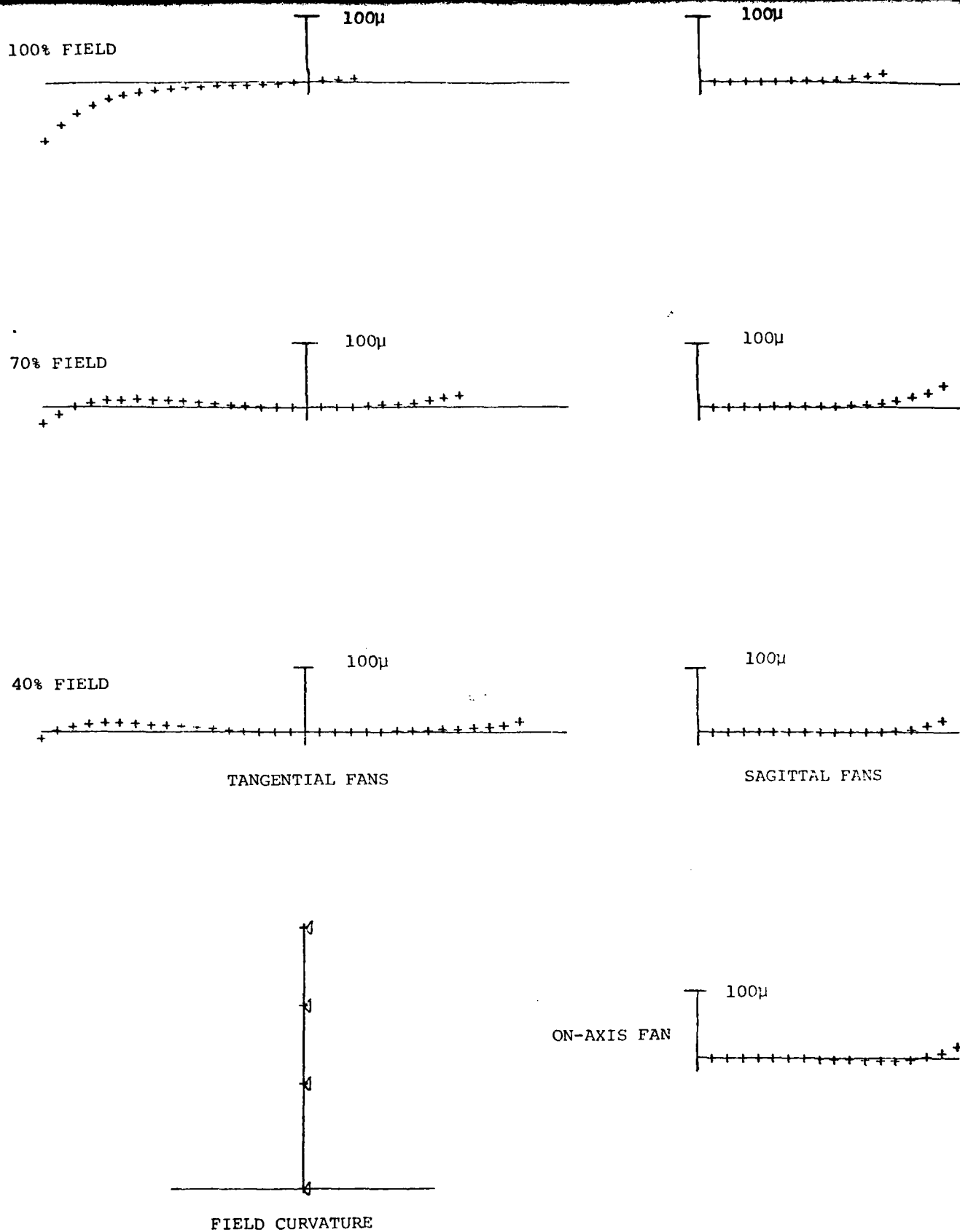
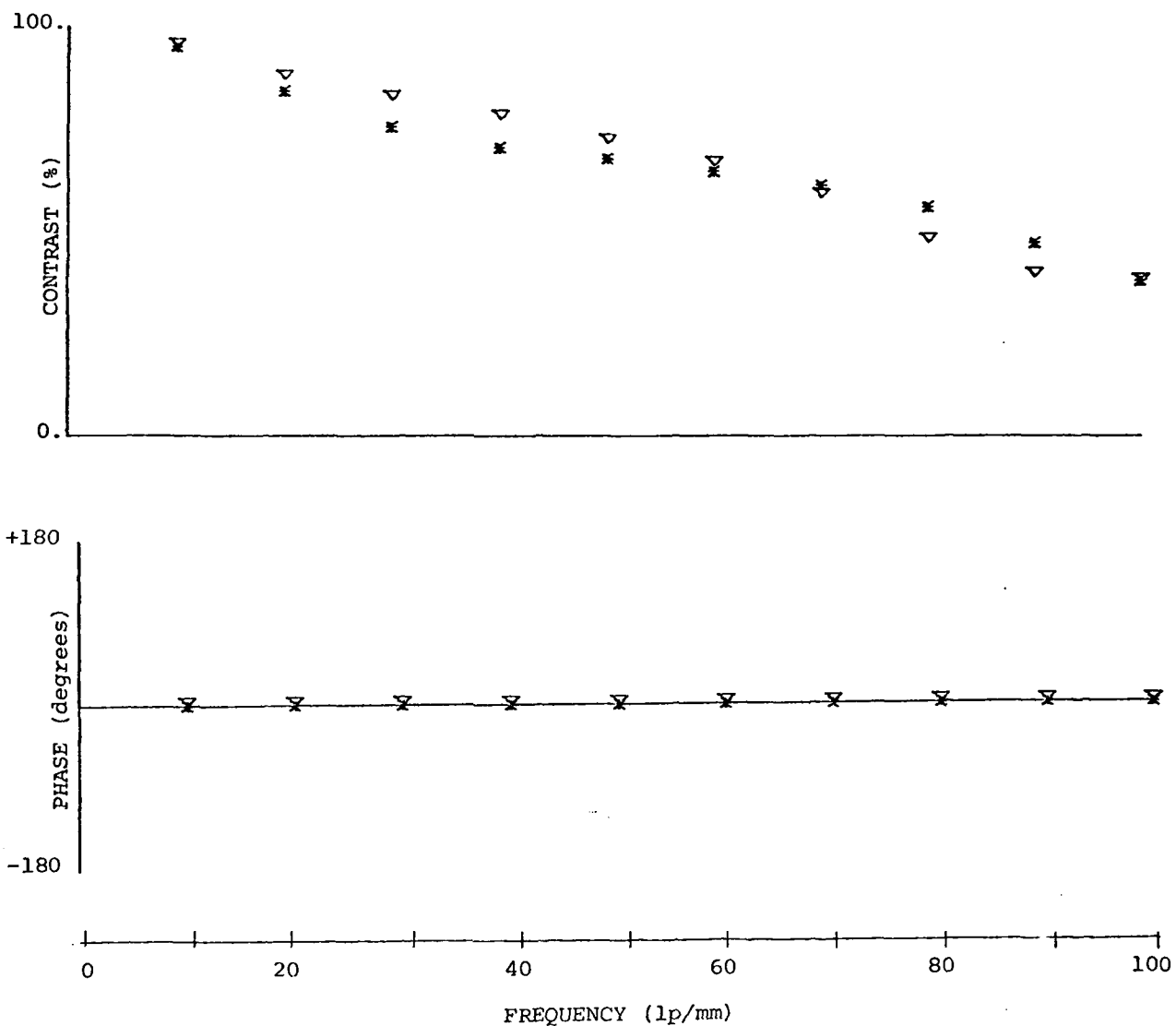
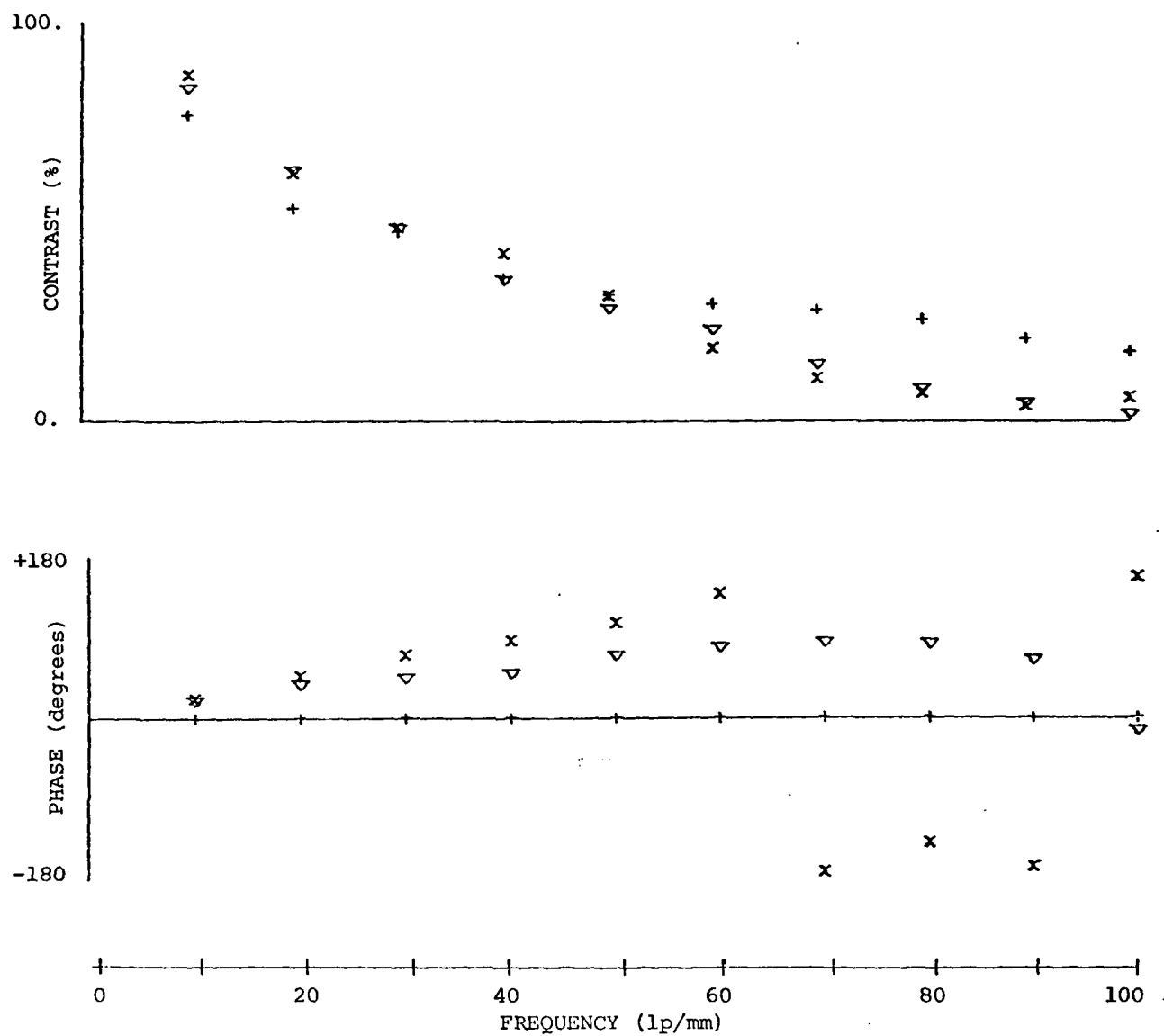


Figure 3-2. Aberration Fan Plots - 12mm Format Objective Lens



	WAVELENGTH(NM)	MTF WEIGHTING
× TANGENTIAL RESPONSE	706.5	40
+ SAGITTAL RESPONSE	546.1	20
∇ 45° RESPONSE	852.1	20

Figure 3-3. On-axis MTF - 12mm Format Objective Lens



	WAVELENGTH (NM)	MTF WEIGHTING
x TANGENTIAL RESPONSE	706.5	40
+ SAGITTAL RESPONSE	546.1	20
v 45° RESPONSE	852.1	20

Figure 3-4. 14° Off-axis MTF - 12mm Format Objective Lens

	Contract Specifications	Baird Design (theoretical)
Format	12mm on fiber optic w/radius of curva- ture $\geq$ 17.5mm	12mm on 20.7mm radius of curvature
Field of View	N.S.*	
Effective Focal Length	17mm	16.88mm
Transmission	94.1% for P-20 phosphor	94% (theoretical)
Distortion	10% pinchshion	10% pincushion
Diopter Range	+2 $\rightarrow$ -6 diopters	+2 $\rightarrow$ -6 diopters
Weight	30 grams maximum	16.2 grams without housing
Outer Diameter	N.S.	18mm maximum without housing
Length	N.S.	42.6mm at 0 diopters (including backfocus and eye relief).
Exit Pupil	7mm minimum	7mm
Eye Relief	14mm minimum	14mm nominal
Optical Backfocus (0-diopters)	N.S.	4.67mm

---

\* Not Specified

Table 3-5. Specifications and Design Results - 12mm Format Dual  
Channel Eyepiece



blurring when the eye shifts position during normal operations. The six air to glass surfaces imply an approximate transmission of 94% (assuming 99% transmission for each surface).

Figure 3-6 shows the aberration fan plots of the eyepiece for a 9mm pupil with the eyepiece focused at 0-diopters.

### 3.1.3 12mm Format Cyclops Eyepiece

Going into this optical design, the intention was to use a reduced number of optical elements and still control system field curvature. The final lens designs of the focusing eyepiece and reimaging lens modules each consist of a doublet and a singlet only, with the collimator having two doublets and two singlets. The focal lengths of all the modules (collimator, reimaging lens, and focusing eyepiece) are approximately equal ( $\sim 17\text{mm}$ ). At this short focal length and small aperture, the reimaging module was designed with a total axial thickness of 9mm, thus fitting in the 20mm available at 58mm interpupillary spacing in an orthogonal configuration. Unlike the 18mm prototype of Section 2, the aerial image between the focusing eyepiece and the reimaging lens need not occur at the elbow mirror, as symmetric field curvature correcting elements are not used.

The exit pupil is 7mm in diameter at 14mm eye relief. To increase the pupil size, the collimator diameter would have to be increased and the pupil sharing mirrors increased in reflecting area, thus increasing system length and weight. Also, more elements in both the reimaging lens and the focusing eyepiece would be needed to provide proper aberration correction over an enlarged

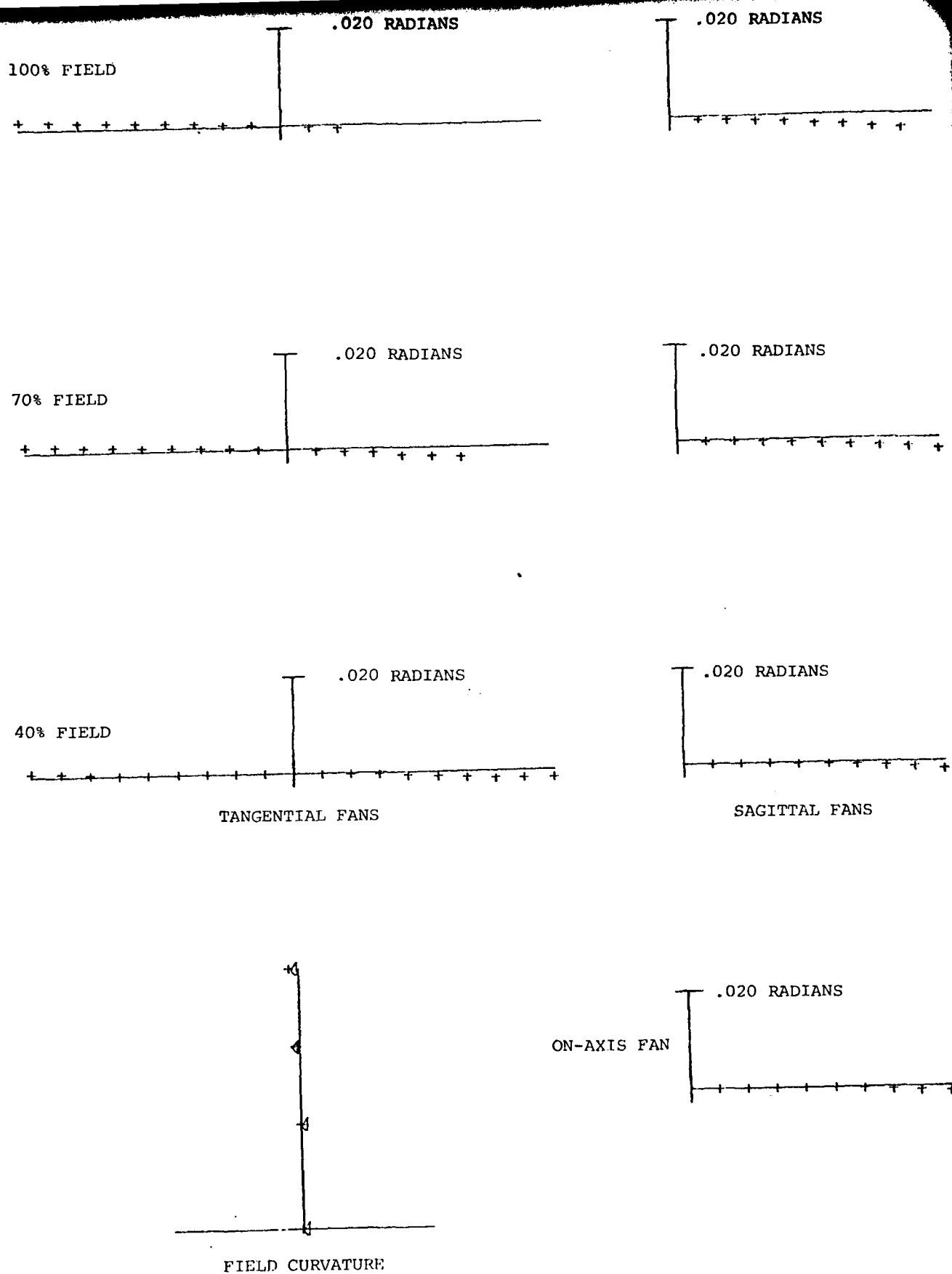


Figure 3-6. Aberration Fan Plots - 12mm Format Dual Channel Eyepiece

pupil. Calculations prove that an increased number of elements (and therefore, increased module lengths) would not permit the right angle configuration to be used. Since the plunging of the eyechannels requires the output angle of the pupil sharing mirror to be orthogonal to the collimator axis, complex elements (reflective and refractive) would have to be used to deflect the light into a folded eyechannel (like that of first cyclops).

Specifications for the cyclops eyepiece, with the design results, are included in Table 3-7. Aberration fan plots for the eyechannel and collimator designs are included in Figures 3-8 and 3-9, respectively. The eyechannel plots were done in the proper configuration (i.e., no inversion), and with the eyepiece focus at 0-diopters.

	<u>Contract Specification</u>	<u>Baird Design</u>
<u>Focusing Eyepiece</u>		
Focal Length	N.S.*	16.88mm
Field of View	N.S.	42.6°
Optical Backfocus (0-diopters)	N.S.	10.15mm
<u>Reimaging Lens</u>		
Focal Length	N.S.	17.17mm
Field of View	N.S.	42.6°
Optical Backfocus (0-diopters)	N.S.	13.25mm
<u>Collimating Lens</u>		
Focal Length	N.S.	17.78mm
Field of View	N.S.	42.6°
Optical Backfocus (0-diopters)	N.S.	1.87mm
<u>Total Eyepiece System</u>		
Format	12mm on radius of curvature $\geq 11.5\text{mm}$	12mm on 11.7mm radius of curvature
Focal Length	17mm	17.57mm
Field of View	N.S.	42.6°
Distortion	10% pincushion	10% pincushion (nominal)
Pupil Diameter	7mm minimum	7mm
Eye relief	14mm minimum	14mm
Field Overlap	N.S.	100%
Interpupillary Range	58 to 72mm	58 to 72mm
Eyepiece Focus Range	+2 to -6 diopters	+2 to -6 diopters
<u>Collimation Error</u>		
Convergence	$\left. \begin{array}{l} + 1^\circ \\ + .5^\circ \end{array} \right\}$	less than .4° total (goal)
Dipvergence		
Weight	70 grams maximum	Approximately 50 grams

\* Not Specified

Table 3-7. Specifications and Design Results - 12mm Format Cyclops Eyepiece

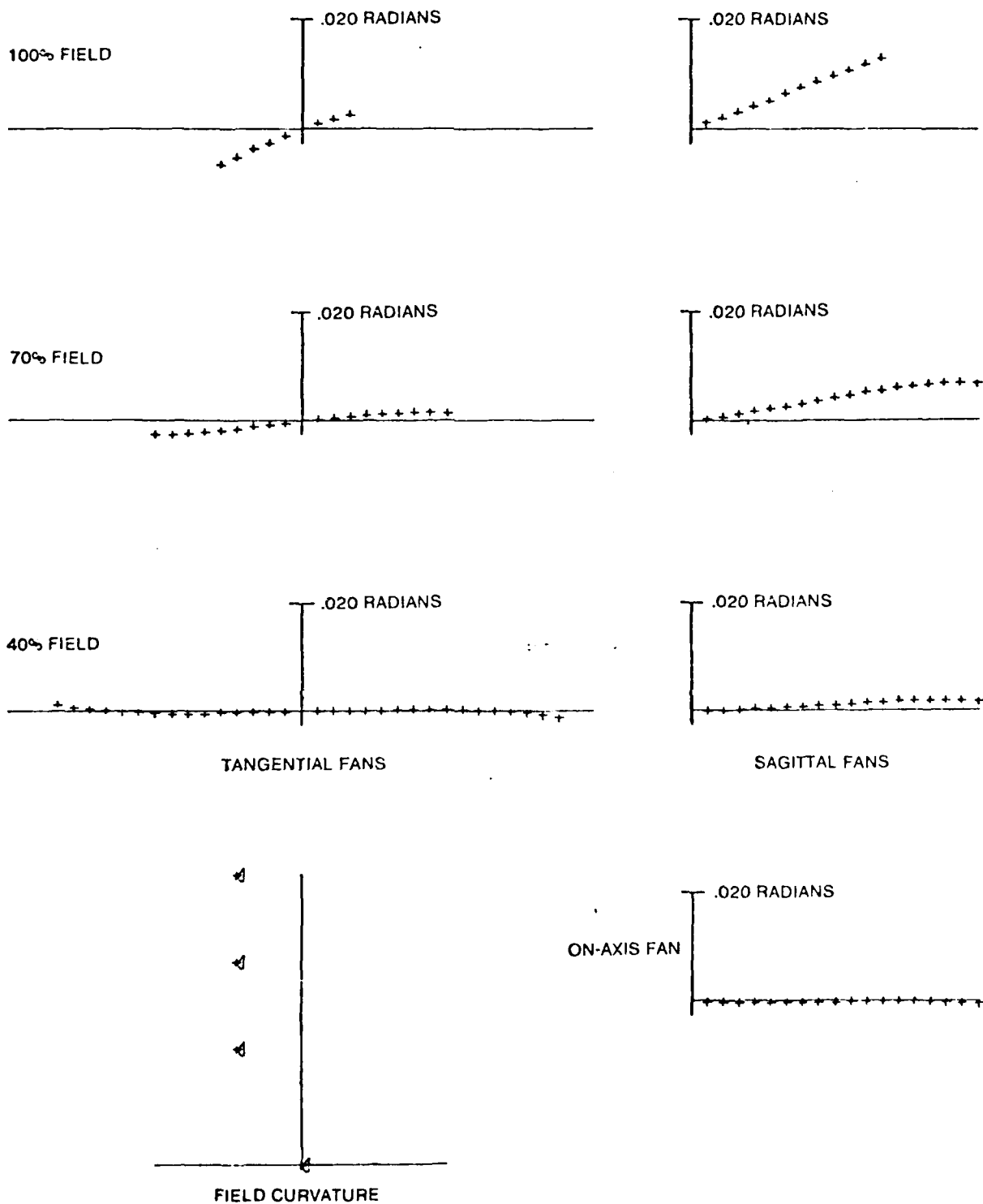


Figure 3-8. Aberration Fan Plots - 12mm Format Cyclops Eyechannel (Focusing Eyepiece with Reimaging Lens)

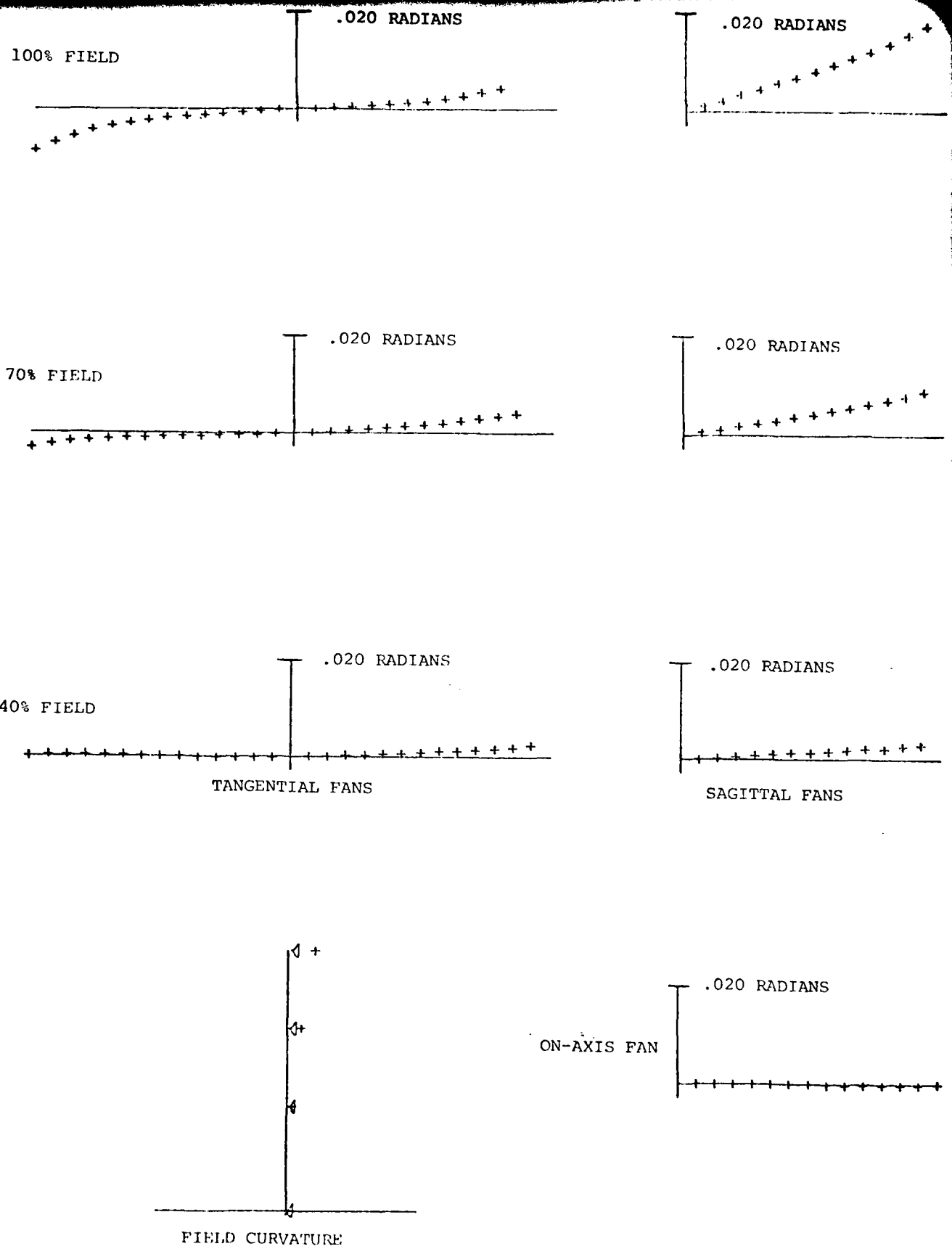


Figure 3-9. Aberration Fan Plots - 12mm Format Cyclops Collimator

### 3.2

#### MECHANICAL DESIGN

To progress toward lighter weight goggles, the dual channel and cyclops systems were designed with lens spacers, barrels, and housings fabricated in plastic. For cost reasons within this contract, a plastic was chosen which could be machined by normal techniques. The plastic used was NORYL 731 (General Electric trade name). Table 3-10 lists the properties of this plastic. Where necessary, for strength and durability reasons, support parts were fabricated in aluminum.

To facilitate changing image intensifier tubes, both systems were designed with a main tube housing barrel into which the objective lens and eyepieces are threaded with appropriate spacer provisions. The tubes can then be installed by removing the eyepieces. The thought behind this is that in eventual production, the main goggle housings can have the image intensifiers integrated. This is cost-effective when low cost (less than \$5. each) main housings are fabricated by injection molding techniques.

##### 3.2.1 12mm Dual Channel Goggle

Figure 3-11 shows a front view of the dual channel goggle. The eyechannels are hinged from a platform which holds the two flat power packs for the tubes. Interpupillary adjustment is achieved by knob rotation which forces the two arms in and out. The two eyechannels are identical; consistent with the idea of modular systems designed for easy maintenance and interchangeable parts.

Specific Gravity, 73°F	1.06
Specific Volume, cu. in./lb.	26.2
Water Absorption, 24 hrs., 73°F, 50% RH	0.066
Heat Deflection Temperature, °F @ 66 psi	279
°F @ 264 psi	265
Thermal Conductivity, BTU/hr/ft <sup>2</sup> /°F/in.	1.50
Coefficient of Thermal Expansion in/in/°F x 10 <sup>-5</sup> (-20° to 150°F)	3.3
Flammability	SE Burns
Dielectric Constant (50% RH, 73°F), @ 60 cps	2.65
@ 10 <sup>6</sup> cps	2.64
Dissipation Factor (50% RH, 73°F), @ 60 cps	0.0004
@ 10 <sup>6</sup> cps	0.0009
Volume Resistivity, dry, ohm cm., 73°F	10 <sup>17</sup>
Surface Resistivity, ohm/sq.	10 <sup>16</sup>
Dielectric Strength (1/8" sample), volts/mil	550
Arc Resistance (Tungsten), sec	75
Tensile Strength, psi @ 73°F	9,600
@ 200°F	6,500
Elongation at Break, % @ 73°F	60
Tensile Modulus, psi @ 73°F	355,000
@ 200°F	230,000
Flexural Strength, psi @ 73°F	13,500
@ 200°F	7,300
Flexural Modulus, psi @ 73°F	360,000
@ 200°F	260,000
Compressive Strength (10% Deformation), psi	16,400
Shear Strength, psi	10,500
Deformation under Load, % @ 2,000 psi, 122°F	0.30
Creep (300 hrs. 73°F @ 2,000 psi), % Strain(e)	0.63
Izod Impact Strength, 1/8" bar. @ 73°F	5.0
Tensile Impact I. Type bars ft. lbs./in <sup>2</sup>	170
Rockwell Hardness	R119
Taber Abrasion, mg.	20
Fatigue Endurance Limit, psi, 2 x 10 <sup>6</sup> cycles	2500
Mold Shrinkage, in/in x 10 <sup>-3</sup>	5-7

Table 3-10. Typical Properties of NORYL 731 (General Electric trade name)



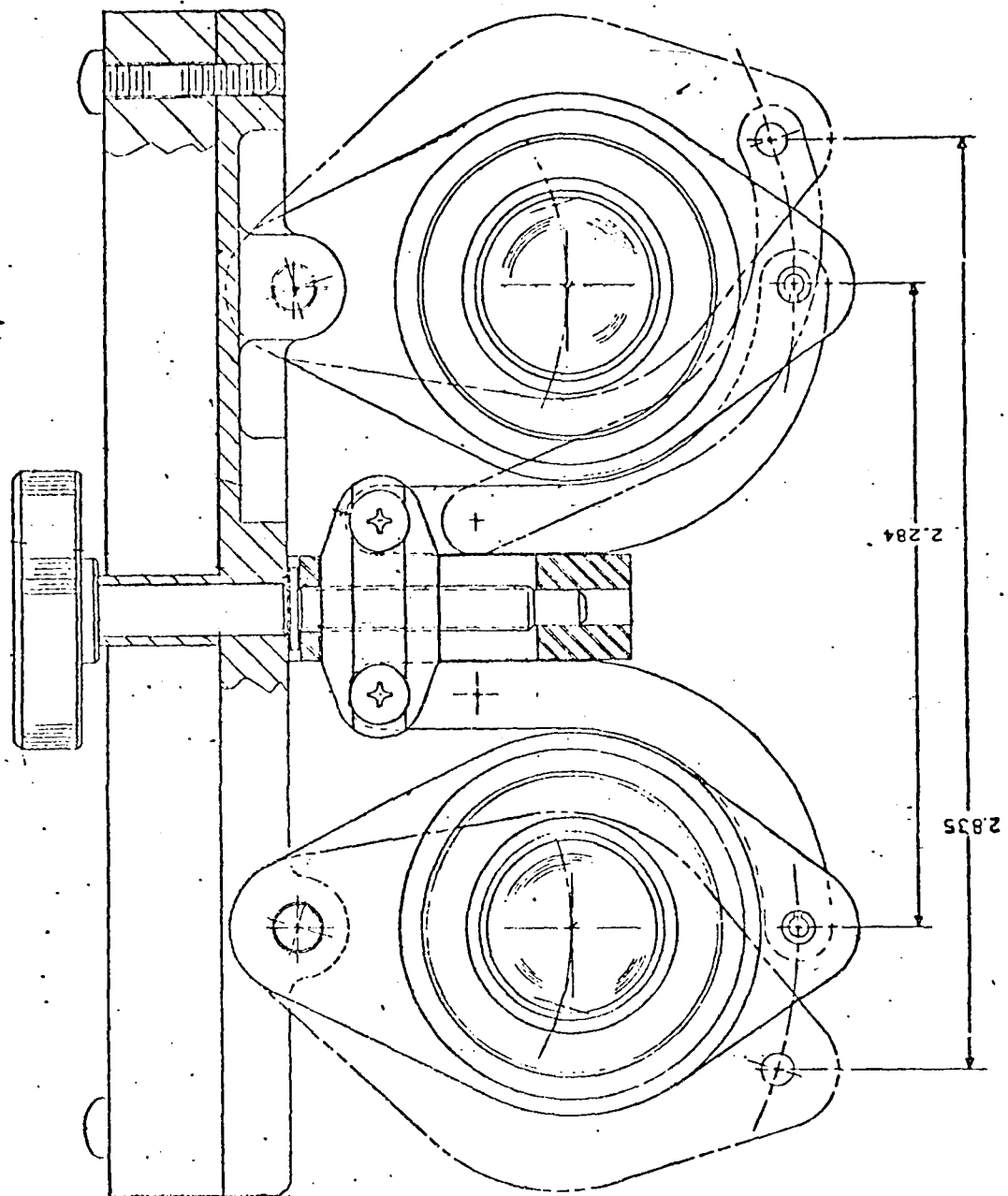


Figure 3-11. Interpupillary Mechanics - 12mm Format Dual Channel Goggle System

To accomodate different intensifier tube lengths and eyepiece backfocus tolerances, a spacer was included in the design which maintains a constant airspace between the intensifier tube and the eyepiece housing (spacer adjusted during the assembly process). When a tube is changed by removing the eyepiece (with spacer), and the new tube inserted, if the sag and centering of the curved output face are correct, the spacer will eliminate problems in overall tube length tolerances. All mechanical parts within each channel assembly are fabricated in NORYL 731. The interpupillary mechanism, with hardware, plus the platform, are aluminum.

### 3.2.2 12mm Cyclops Goggle

Several new features were designed into this 12mm cyclops system to avoid the problem noted on the first prototype cyclops eyepiece. A conceptual diagram of the interpupillary mechanism is provided in Figure 3-12 with the total assembly shown in Figure 3-13.

A small prism, with external reflecting surfaces, is used to share the collimator output between the two eyechannels. This eliminates the problem of aligning two independent mirrors and establishes an angular accuracy limited only by optical fabrication techniques as they apply to prisms. This prism is an integral part of the collimator barrel assembly.

The collimator assembly, with prism, is installed by insertion into the main eyepiece housing and retained by set screws. The collimator may be rotated prior to the seating of the set screws. The elbow mirror and reimaging lens of each eyechannel are integrated into a single assembly. This entire module can be translated

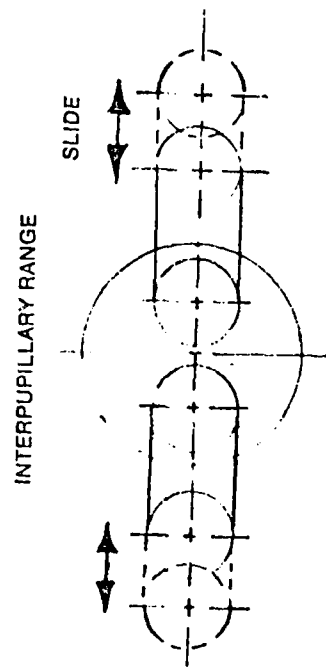


Figure 3-12. Sliding Interpupillary Adjustment Mechanism

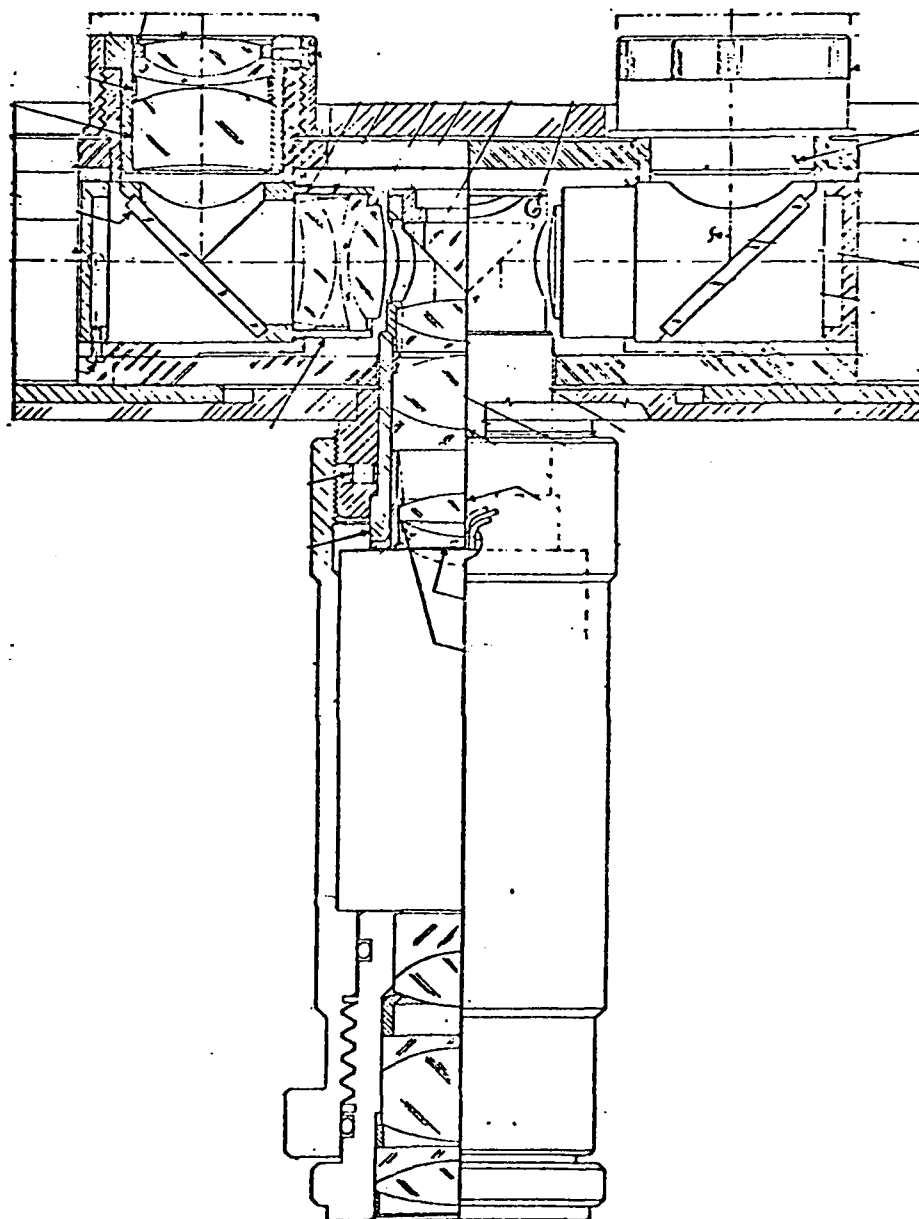


Figure 3-13. Mechanical Layout - 12mm Format Cyclops System

and rotated during assembly and alignment, thus providing a means for eliminating image twist and aligning the reimaging lens axis with the focusing eyepiece axis.

The combination of these facilities (collimator rotation and reimaging lens barrel translation and rotation), provide all adjustment necessary for alignment within the eyepiece.

Once aligned, the eyechannels, plus the collimator become an independent eyepiece system which threads into the main barrel housing containing the image intensifier tube. The objective lens similarly threads into the other side. An external spacer for the eyepiece, designed to accomodate the deviation in back-focus due to optical and intensifier tube tolerances, mounts between the intensifier housing and the eyepiece main housing.

The entire system was designed to mount at the flanges on the eyepiece (See Figure 3-14). The wall thicknesses of the housing were increased to provide for support of the system.

### 3.3 RESULTS

Prior to system integration, all components were examined for agreement with the optical design. All were tested for effective focal length, and optical quality (via spot size versus field measurements), and found to comply with the design.

The prototype 12mm tubes were not available for assembly tests. Night Vision Laboratory supplied fiber optic tube approximators of equivalent length for checking the final assemblies. The dual channel tube approximators were fiber optic twistors providing the proper image inversion.

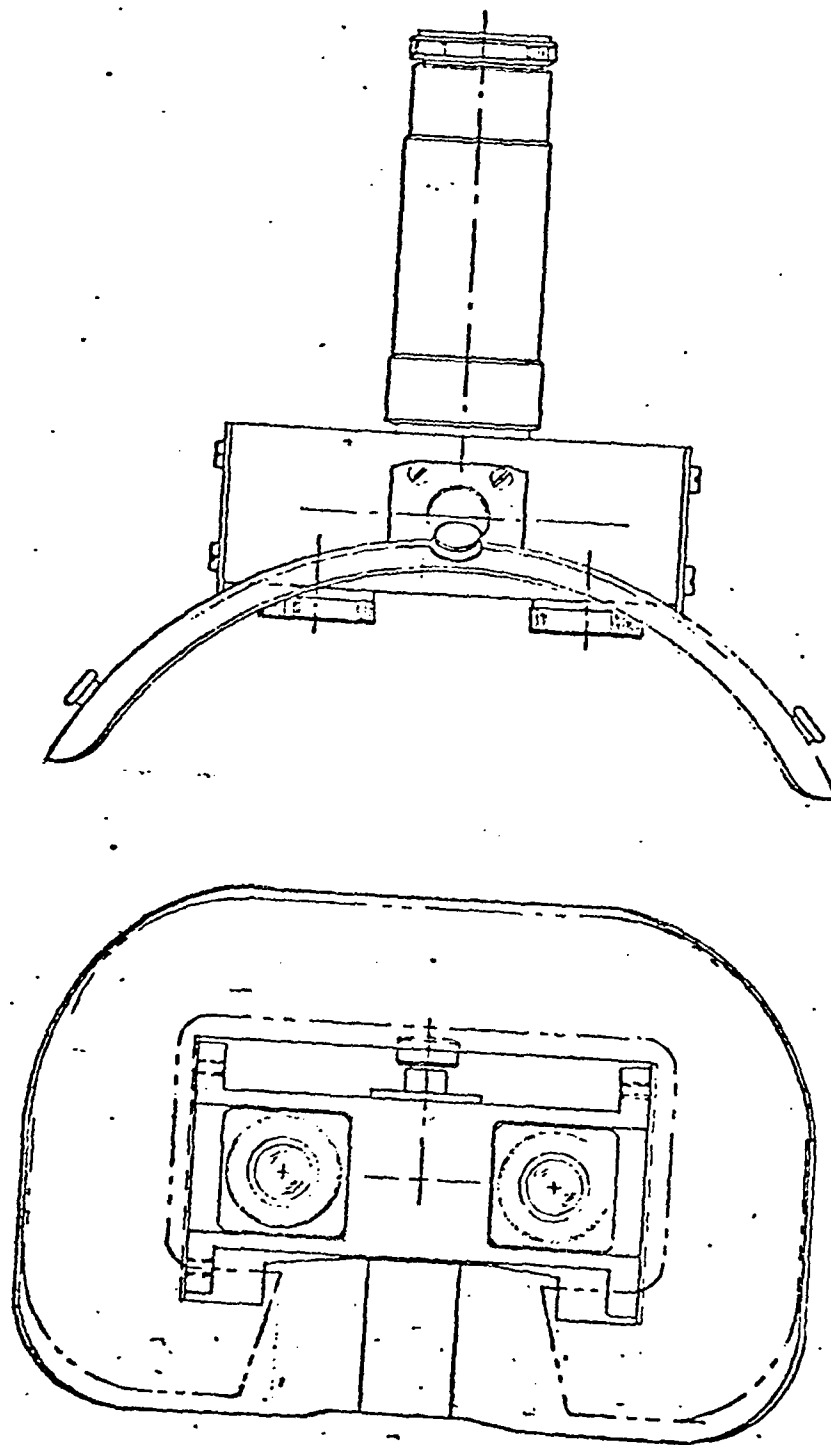


Figure 3-14. Mask Mounted 12mm Cyclops Goggle System

### 3.3.1 12mm Dual Channel Goggle

Figure 3-15 shows the component assemblies of the dual channel system.

The tolerances imposed on the hinge points of the platform and the mounts of the two eyechannels proved adequate to control parallelism of the two eyechannels. The centering error of the input face to the output face of the tube to its outer diameter proved to be a residual effect for which no adjustment was supplied, though the system collimation error of the delivered units was within tolerance. Both units supplied measured less than  $.5^{\circ}$  total collimation error.

The first unit fabricated weighed approximately 525 grams. Attempts at lightening by machining away unnecessary material accomplished a reduction to about 500 grams. A second interpupillary drive mechanism modeled after a draftman's compass was installed on the second unit delivered to further reduce the system weight and the number of parts. A diagram is included in Figure 3-16. Installation of this reduced the system weight to about 400 grams. Note that these weights include facemask head-strap, facepad, and the two fiber optic assemblies used to approximate tubes.

Resolution tests performed in room light with the fiber optic tube approximators indicated a system resolution of approximately 63 lp/mm, thus providing an ample cushion over the expected tube resolution. Low light level tests of contrast versus light level were not performed because of the restricted numerical

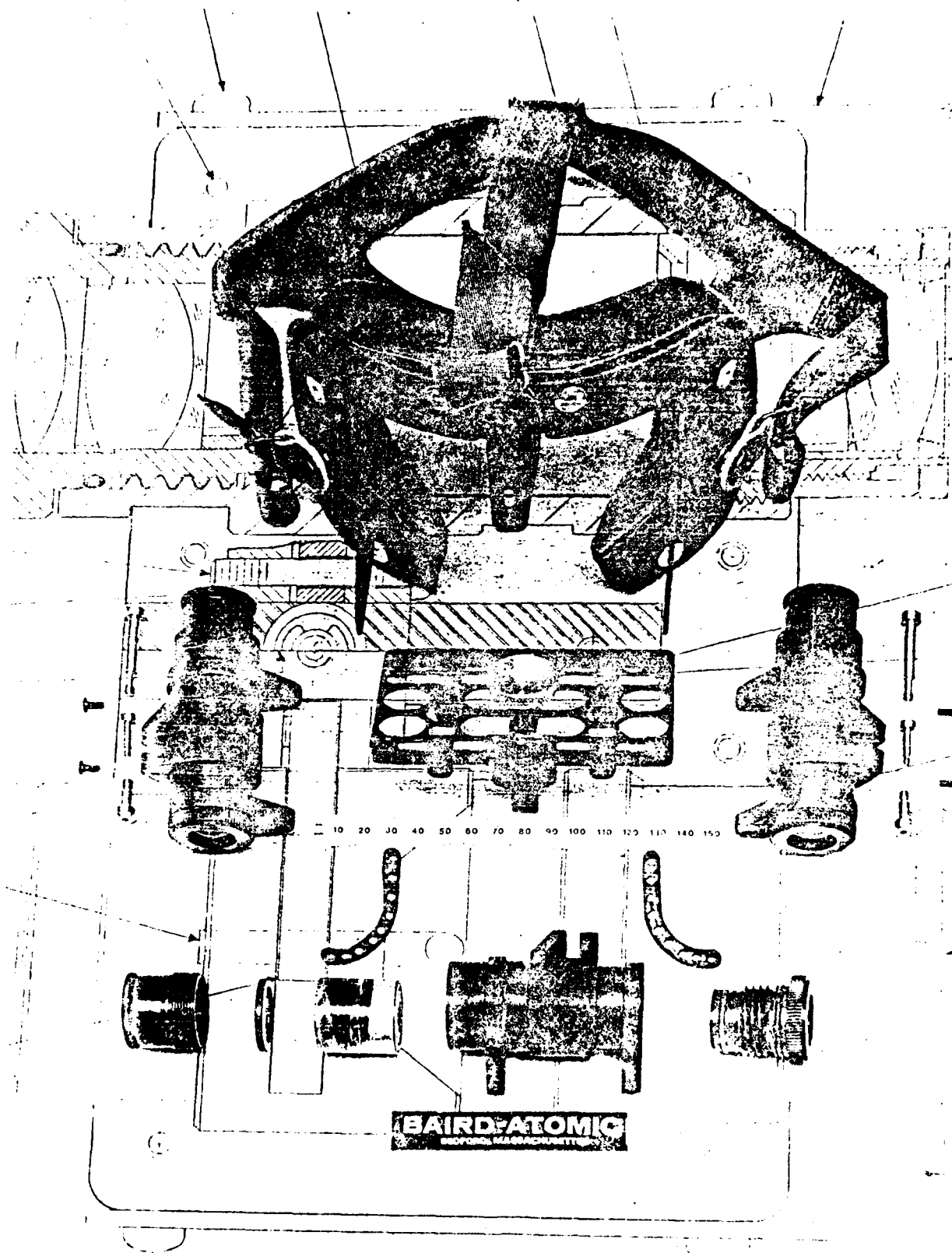


Figure 3-15. 12mm Dual Channel Goggle System Components



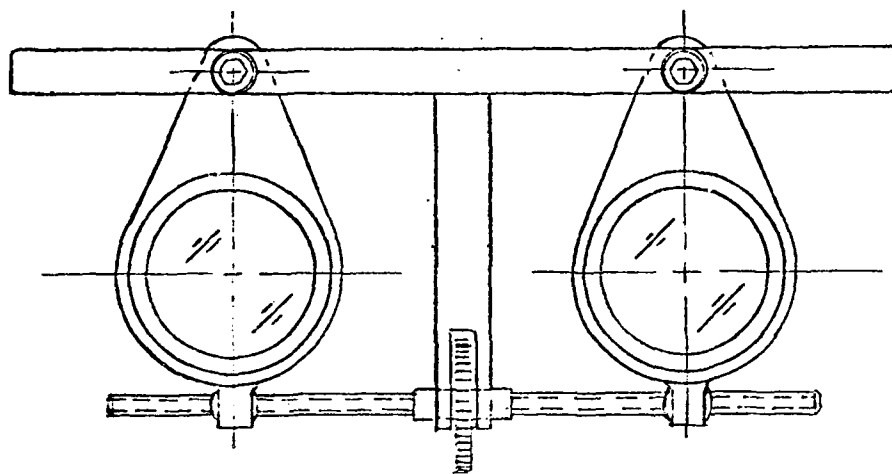


Figure 3-16. 12mm Dual Channel Goggle System Alternate Interpupillary Adjustment Mechanism

aperture of the light output by the fiber optic tube approximators. This was already in evidence in room lights by the energy fall-off seen at the edges of the field.

In walking, running, and during normal operation, the goggle pupils and eye relief proved adequate. Eyeball motion within these pupils did not show blurring, indicating adequate aberration correction over the entire exit pupil.

### 3.3.2 12mm Cyclops

Figure 3-17 is a photograph of the finished cyclops system. The mechanical features discussed in Section 3.2.2, designed to overcome previously experienced problems, resulted in the uncomplicated alignment of the 12mm cyclops systems. By sequentially rotating the collimator (with prism) until the axiis were projected in the eyepiece plane, rotating the individual re-imaging modules (with elbow mirrors) to eliminate image twist and then translating these modules until the images in each channel merged when viewed normally, collimation to better than  $.5^\circ$  was easily achieved.

As observed in the dual channel system, the output numerical aperture of the fiber optics supplied by NVL to approximate the tubes was insufficient to fill the pupils. An energy fall-off existed at the edges of the field. To an individual eye looking right and left, this is more evident on one side of the tube output than the other, because the off-axis chief ray angle at the tube output is steeper for the eye when looking toward the outside (e.g., right eye looking right). With the full numerical aperture capability of the curved fiber optic output unfilled (objective lens does not fill N.A. and losses exist because of length), and the

inherent deflection of the light energy away from the optical axis; the pupil which views the tube at the steeper angle is not filled. In actual use with an image intensifier tube, the output phosphor completely fills the fibers, providing sufficient light energy at the steeper ray angle and therefore, a less evident brightness fall off.

The picture presented by this goggle was good. The entire 12mm tube output was presented to each eye with no detrimental field curvature or astigmatism effects at the periphery of the tube. The 7mm exit pupil at 14mm eye relief proved adequate when walking, running or during other normal operations, and no image blurring occurred as the eye position in the pupil was changed. Detailed resolution tests were not performed on the delivered units because of the unknown influence of the fiber optic tube output.

In general, the 12mm cyclops system demonstrated that miniaturization of the cyclops type of goggle system is feasible without loss of system throughput or imaging characteristics. In addition, the plunging interpupillary mechanism exhibited desirable characteristics related to system alignment, complexity, and sealability.

This work was an investigation of the wide angle capabilities of cyclops eyepieces. Two designs were developed for coupling to noninverting image intensifier tubes in 18mm and 25mm formats with two units of each format fabricated.

Preliminary design analysis demonstrated that approximately a  $55^\circ$  field of view was possible. Experience gained during the optical design phases of the first 18mm cyclops (Section 2.0), and the 12mm cyclops (Section 3.0), indicated that the wide angle is best achieved by designing the collimator for a  $40^\circ$  field of view (independent of format), and the reimaging lens and focusing eyepiece, such that, in a back-to-back configuration, they provide the angular magnification necessary to achieve the  $55^\circ$ . This amounts to having the shortest focal length in the focusing eyepiece. Using this approach, each of the two systems were configured to use a common eyechannel design.

Utilization of the plunging interpupillary adjustment method of the 12mm format  $40^\circ$  field of view cyclops goggles was reviewed, but at a close interpupillary setting, too little space is available for the optical elements required. A method, different from those previously used, was devised employing a single hinge point. As shown in Figure 4-1, the two eyechannel entrance pupils are rotated about the collimator axis during interpupillary adjustment. The eyechannel pupils are always offset a constant distance from the collimator axis.

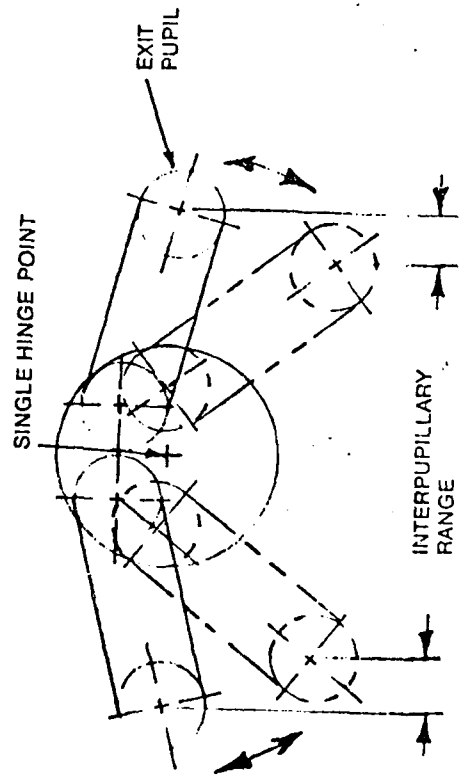


Figure 4-1. Single Hinge Point Interpupillary Adjust Mechanism

#### 4.1 OPTICAL DESIGN

##### 4.1.1 18mm and 25mm Wide Angle Cyclops Eyepieces

To take advantage of the cancellation properties of the back-to-back configuration in the eyechannel, more optical elements are required in the shorter focal length, wider angle focusing eyepiece. This is necessary to make the aberrations, as a function of height in the intermediate image plane, comparable to those of the narrower field, longer focal length reimaging module. The final lens designs for these two modules contain a doublet and a singlet in the reimaging assembly and two doublets and a singlet in the focusing eyepiece. The aberrations are shown in the fan plots of Figure 4-2. These plots are for an 8mm pupil and  $56.9^\circ$  field of view with the eyechannel set afocal (i.e., zero diopter focus). Note that even with the wider angle, the aberrations are not unlike those presented earlier for the  $40^\circ$  eyechannels.

It has been hoped that, because of the common eyechannel design and commonality of collimator output angles, the 18mm collimator design could be scaled for use in the 25mm system. This cannot be done in the optical design sense, because scaling to the 25mm format increases the Petzval radius (decreasing field curvature) and reduces astigmatism, thus decreasing the amount of "in-the-bank" aberrations required to counter balance residual eyechannel aberrations. To maintain the critical balance, two distinct designs were developed, each containing two doublets and two singlets. The aberrations for these collimators (Figures 4-3 and 4-4) have more over-corrected field curvature than the

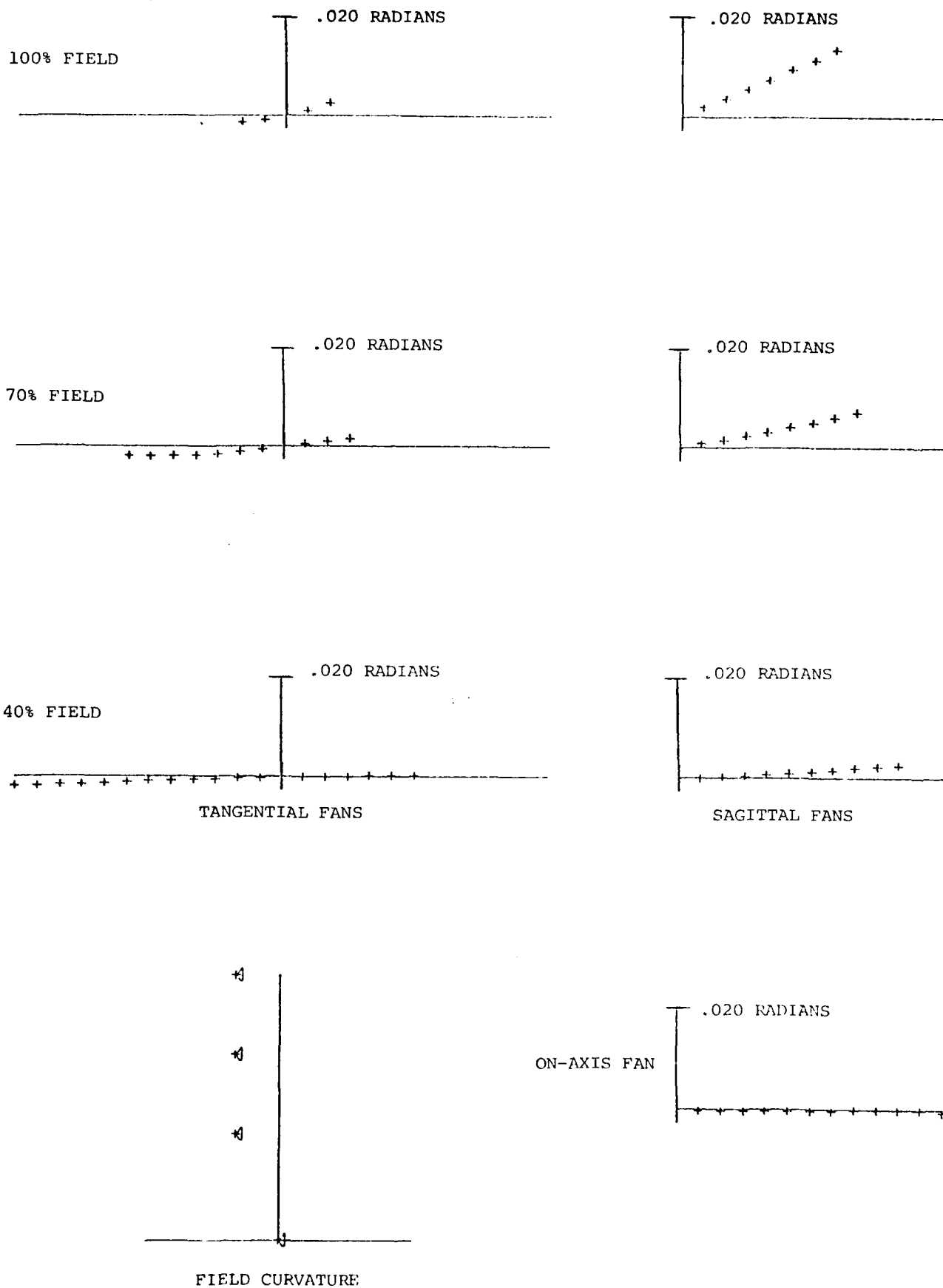
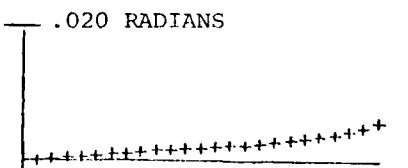
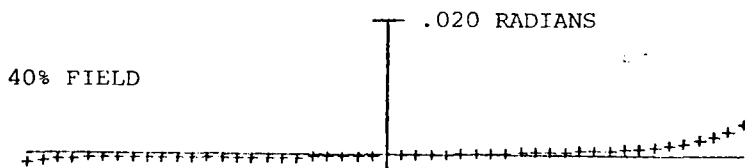
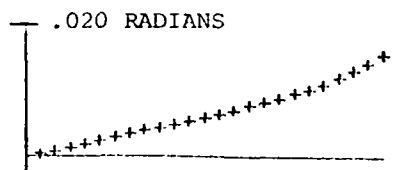
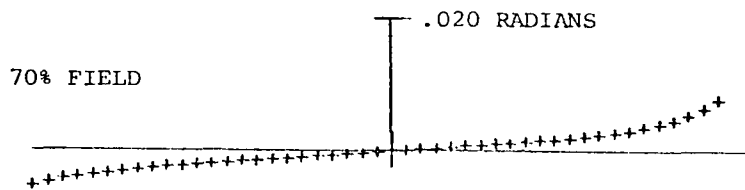
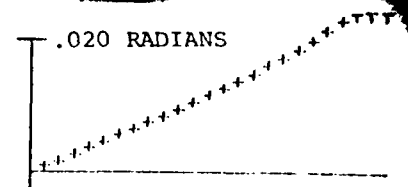
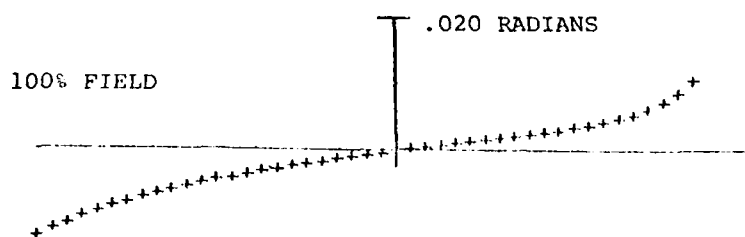
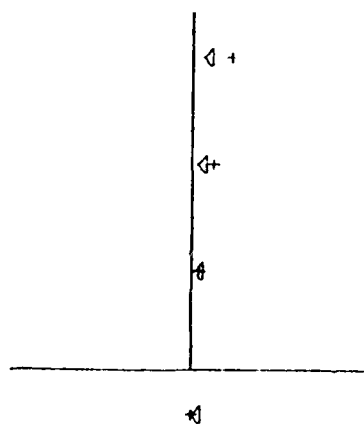


Figure 4-2. Aberration Fan Plots - 18mm and 25mm Wide Cyclops Eyechannel



TANGENTIAL FANS

SAGITTAL FANS



FIELD CURVATURE

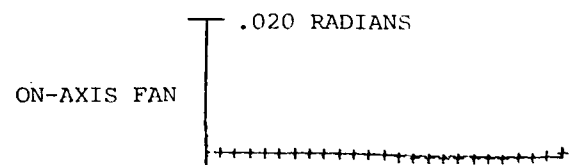
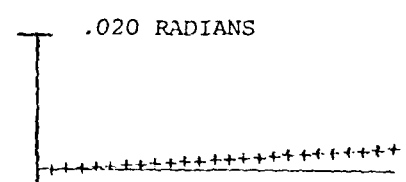
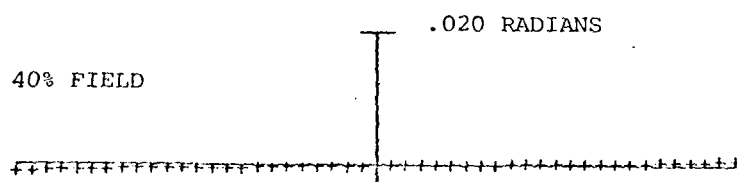
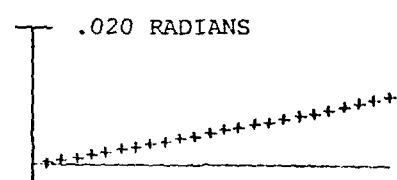
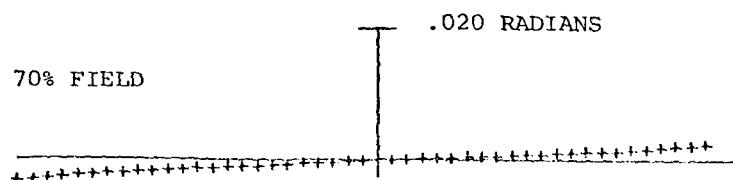
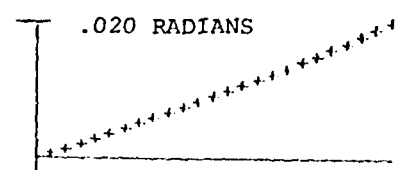
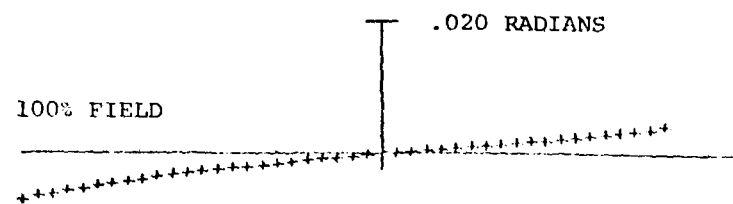


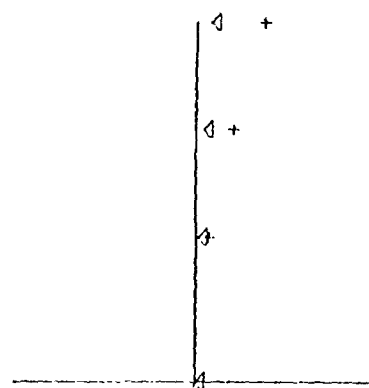
Figure 4-3. Aberration Fan Plots - 18mm Wide Angle Cyclops Collimator





TANGENTIAL FANS

SAGITTAL FANS



FIELD CURVATURE

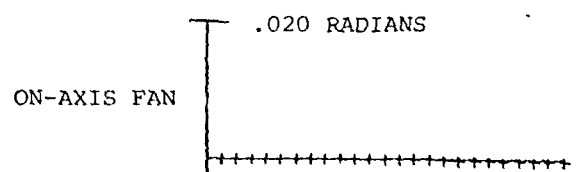


Figure 4-4. Aberration Fan Plots - 25mm Wide Angle Cyclops Collimator

40° collimators of earlier systems (indicated by increased slopes of tangential and sagittal fans. This compensates for the residual effects of the shorter focal length focusing eyepiece module. Both collimators have sufficient aperture to accomodate two de-centered 12mm pupils.

Tables 4-5 and 4-6 list the contract specifications with Baird's design results for the 18mm and 25mm format cyclops eyepieces respectively.

## 4.2 MECHANICAL DESIGN

### 4.2.1 18mm and 25mm Wide Angle Cyclops Eyepieces

An exploded diagram of the mechanical eyepiece configuration is shown in Figure 4-7. The two eyechannels were designed to accomodate either the 18mm or 25mm collimator, as the threaded mount is common to both.

To reduce the number of degrees of freedom, one eyechannel is fixed to the collimator. Provision is made for th other eyechannel to rotate through the angle required to achieve a 55 to 72mm interpupillary range. The collimator (and attached intensifier tube and objective lens), rotate as the spacing is set. As in the case of the 18mm feasibility model cyclops eyepiece, the rotation leads to a void where the eyechannels fold together. The possibility of sealing this was investigated, but the cost for fabrication versus the relative effectiveness did not warrant the effort at this investigative level of work.

A section drawing of the eyechannels, as viewed by the collimator, is included in Figure 4-8. As adjustment is made to the minimum interpupillary spacing, the triangular shaped

	<u>Contract Specification</u>	<u>Baird Design</u>
<u>Focusing Eyepiece</u>		
Focal Length	N.S.*	19.05mm
Field of View	N.S.	56.9°
Optical Backfocus	N.S.	6.47mm
<u>Reimaging Lens</u>		
Focal Length	N.S.	27.2mm
Field of View	N.S.	42.6°
Optical Backfocus	N.S.	22.10mm
<u>Collimating Lens</u>		
Focal Length	N.S.	26.58mm
Field of View	N.S.	42.6°
Optical Backfocus	N.S.	3.91mm
<u>Total Eyepiece System</u>		
Format	18mm	18mm on 14.5mm radius of curvature
Focal Length	18 ± 1mm	18.62mm
Field of View	N.S.	56.9°
Distortion	N.S.	11% pincushion (nominal)
Pupil Diameter	N.S.	8mm
Eye Relief	N.S.	15mm
Overlap	100%	100%
Interpupillary Range	55 to 72mm	55 to 72mm
Eyepiece Focus Range	+2 to -6 diopters	+2 to -6 diopters
<u>Collimation</u>		
Convergence	N.S.	± 1.0° (goal)
Dipvergence	N.S.	± .5° (goal)

\*Not Specified

Table 4-5. Specifications and Design Results - 18mm Wide Angle Cyclops Eyepiece

	<u>Contract Specification</u>	<u>Baird Design</u>
<u>Focusing Eyepiece</u>		
Focal Length	N.S.*	19.05mm
Field of View	N.S.	56.9°
Optical Backfocus	N.S.	6.47mm
<u>Reimaging Lens</u>		
Focal Length	N.S.	27.2mm
Field of View	N.S.	42.6°
Optical Backfocus	N.S.	22.0mm
<u>Collimating Lens</u>		
Focal Length	N.S.	38.22mm
Field of View	N.S.	42.6°
Optical Backfocus	N.S.	6.79mm
<u>Total Eyepiece System</u>		
Format	25mm	25mm on 18mm radius of curvature
Focal Length	27.0 $\pm$ 1.5mm	27.62mm
Field of View	N.S.	55.4°
Disortion	N.S.	11% pincushion (nominal)
Pupil Diameter	N.S.	8mm
Eye Relief	N.S.	15mm
Overlap	100%	100%
Interpupillary Range	55 to 72mm	55 to 72mm
Eyepiece Focus Range	+2 to -6 diopters	+2 to -6 diopters
<u>Collimation</u>		
Convergence	N.S.	$\pm$ 1.0° (goal)
Dipvergence	N.S.	$\pm$ .5° (goal)

\* Not Specified

Table 4-6. Specification and Design Results - 25mm Wide Angle Cyclops Eyepiece

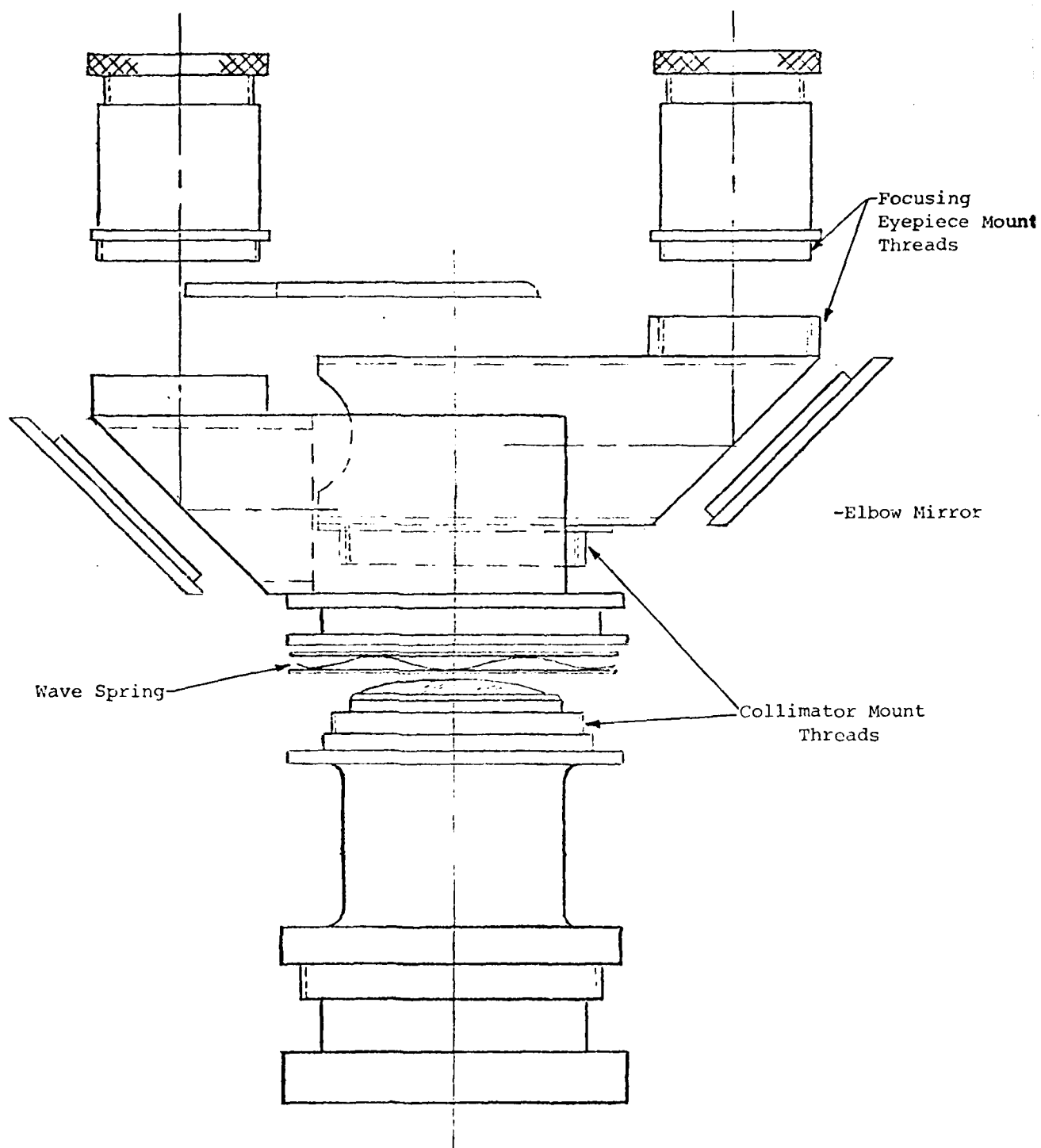


Figure 4-7. Mechanical Configuration - 18mm and 25mm Wide Angle Cyclops Systems

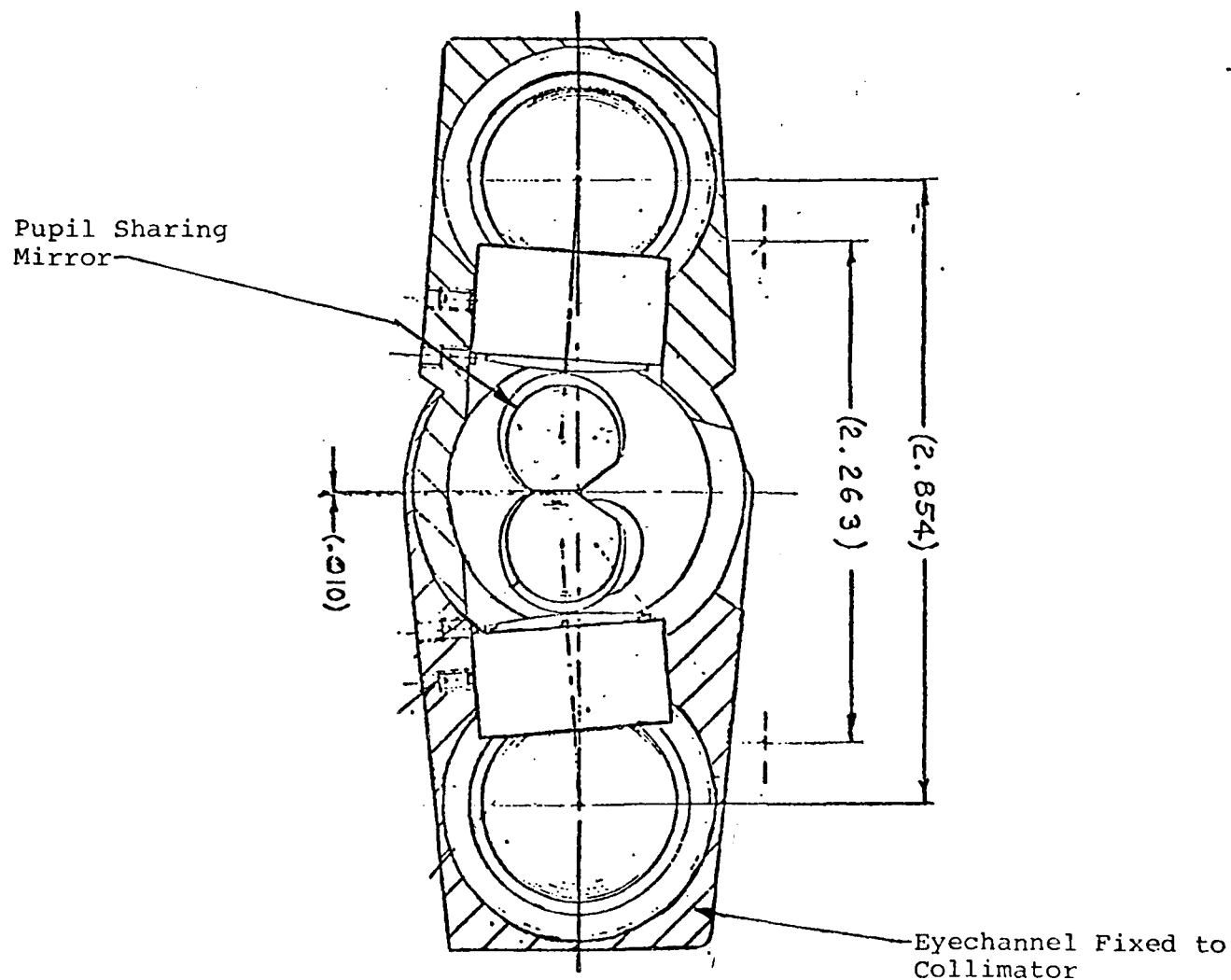


Figure 4-8. Section View of Eyechannel - 18mm and 25mm Wide  
Angle Cyclops Eyepieces

void shown between the pupil sharing mirrors closes and a similar spacing opens where the mirrors are currently in contact. These mirrors, which define the axial pupil size, nearly make contact at the extrema of the 55 to 72mm adjustment range.

To interface these units to intensifier tubes, two dimensions must be maintained; these are:

- 1) system centering
- 2) system backfocus

Figures 4-9 and 4-10 provide the necessary information to maintain these dimensions. The backfocus reference dimensions given are theoretical. Adjustments may have to be made during interfacing to maintain the collimators at their infinity backfocus.

#### 4.3 RESULTS

##### 4.3.1 18mm and 25mm Wide Angle Cyclops Eyepieces

Throughout the assembly process, subassemblies were examined for compliance with the theoretical designs. After final alignment, each of the units were measured for field of view, system focal length, collimation error, and picture quality. A photograph of the two systems is shown in Figure 4-11.

Examination of the first two pair of eyechannels revealed that more alignment freedom was necessary to reduce system collimation error. The necessary facility was provided by reworking the mounts of the focusing eyepiece modules, such that, translation in the plane orthorgonal to their axiis was possible. This permitted eyepiece centering on the axiis projected by the elbow

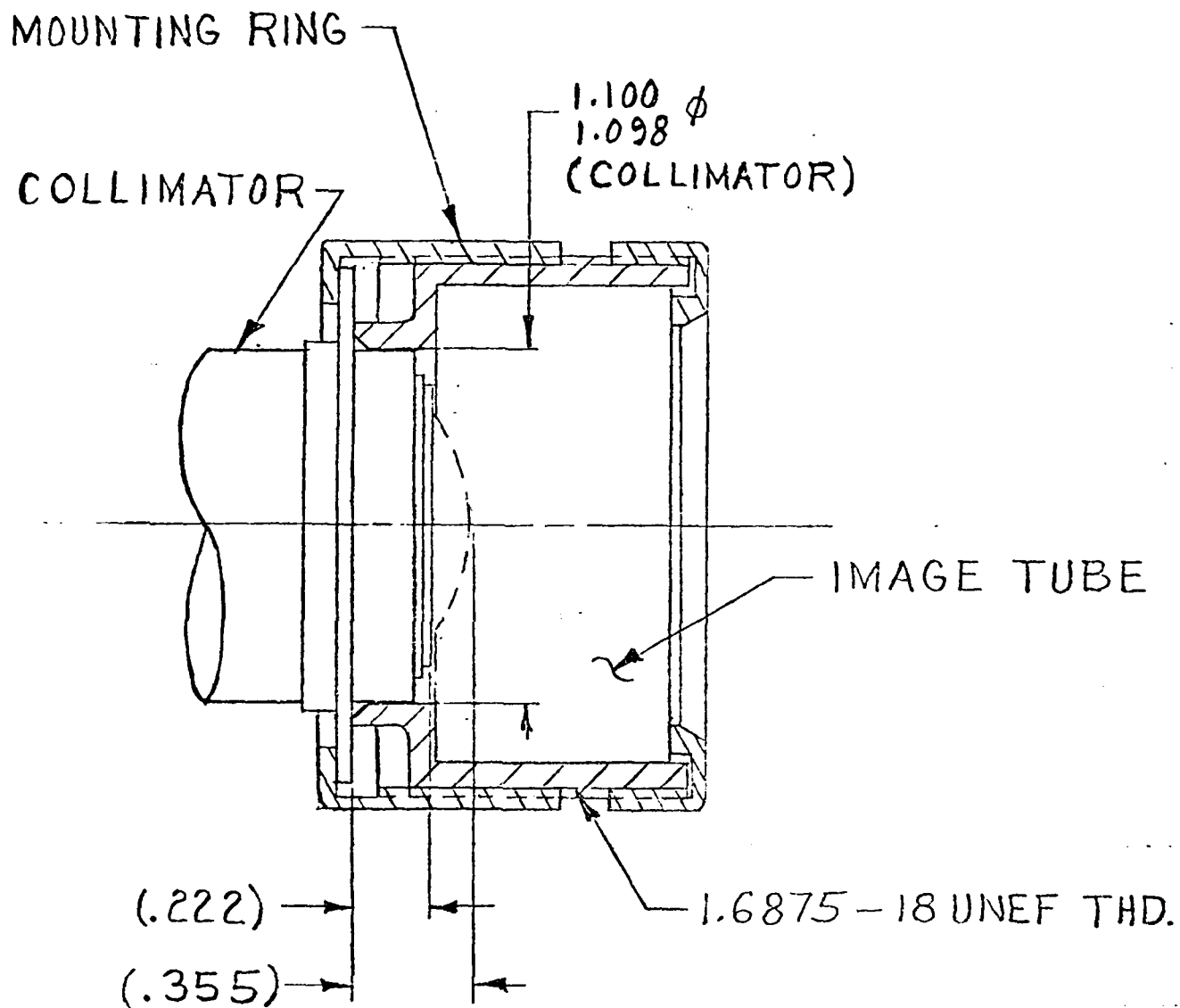


Figure 4-9. Interface Dimensions - 18mm Wide Angle Cyclops Eyepiece



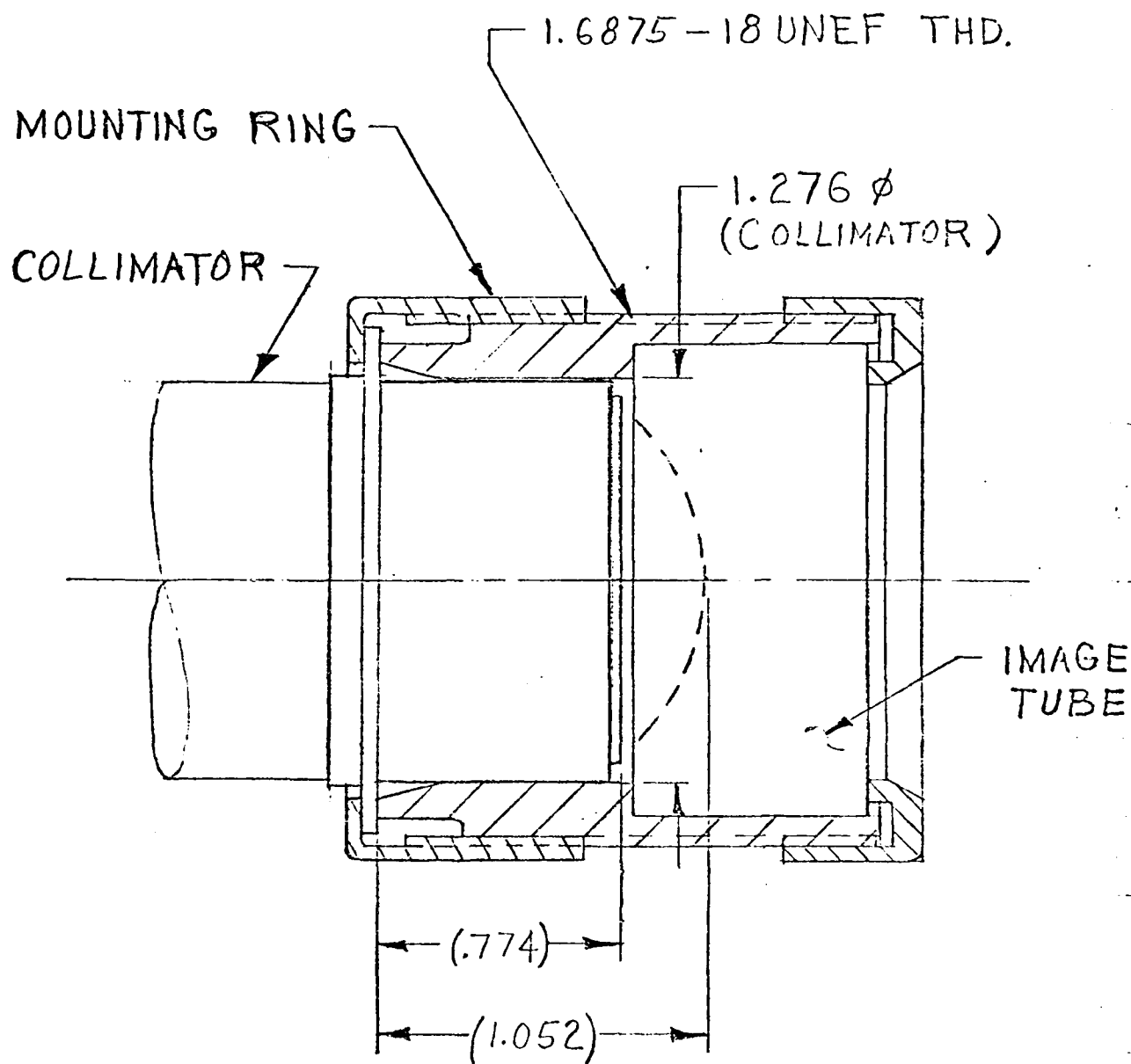


Figure 4-10. Interface Dimensions - 25mm Wide Angle Cyclops Eyepiece

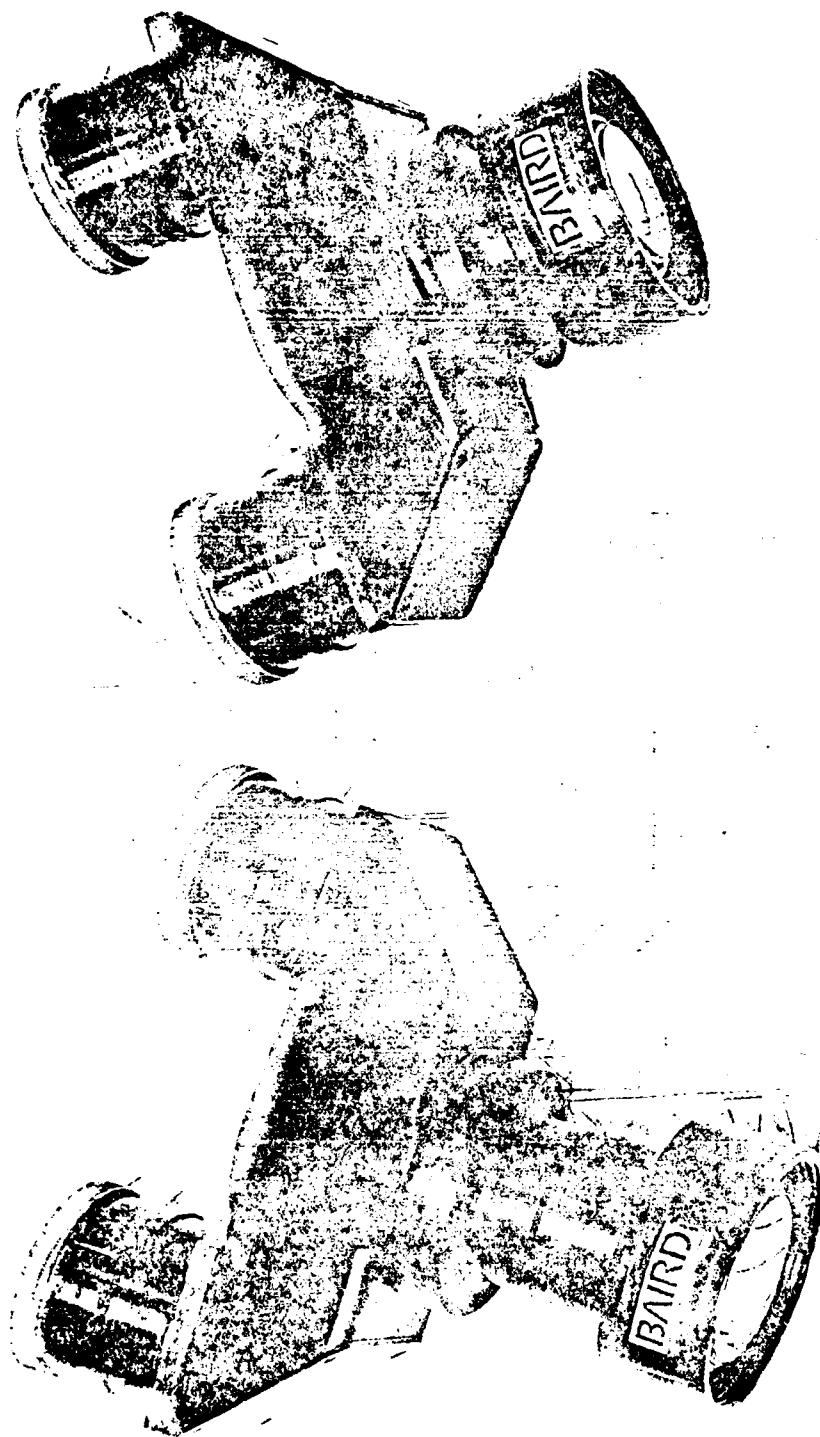


Figure 4-11. 18mm and 25mm Wide Angle Cyclops Eyepieces

mirrors. Final measurements with the eyepieces set at 0-diopters gave convergence errors between  $.81^{\circ}$  and  $.63^{\circ}$  and dipvergence errors between  $.13^{\circ}$  and  $.33^{\circ}$ . All of these are within the desirable  $\pm 1^{\circ}$  convergence,  $\pm .5^{\circ}$  dipvergence boundaries.

Transmission measurements on the systems indicated approximately 72% transmission for the 25mm format and 70% for the 18mm format. The different values obtained are attributable to experimental error and the difference in glasses between the two different format collimators.

It should be noted that the 25mm collimator delivered had a modification from the original design. Night Vision Laboratory project personnel noted that with 18mm radius of curvature on the 25mm format tube output faceplate for the 25mm format, total internal reflection in the fibers limits the viewing angle at the edges of the field. Baird analyzed this and confirmed the phenomena. The impact on the system design was that the chief ray from the pupil which views the output at the steeper angle was not filled. Detailed analysis of the optical design revealed that if the distance between the 25mm collimator aperture and the reimaging lens is increased, the chief ray angle is decreased sufficiently to intersect the output cone from the edge fibers. Hence, a 7mm spacer is incorporated near the collimator output aperture in the delivered 25mm format units.

In the absence of image intensifier assemblies with the properly curved output faceplates, Baird fabricated a fixture which housed fiber optic wafers of the proper format and curvature for examining the picture quality of the eyepieces. These fixtures were setup to hold transparencies with back-illumination.

The pictures presented by each of the systems were comparable. The full format was easily viewed by each eye (when properly back lit), confirming 100% overlap. Resolution was adequate to resolve the details of the fiber optics over the entire field. Residual astigmatism and field curvature was evident at the very edges of the field, but appeared to be adequate for recognition of peripheral field objects.

Pupil diameter and eye relief appeared to be "roomy." Baird personnel who used the eyepieces, moved in and out and side to side while viewing and experienced no significant resolution loss or confusion because of "floating pupils." These statements should be qualified, in that, the recurring problem of filling the numerical aperture of the fiber optic faceplate test fixtures was present during examination. The adequacy of the pupils will likely be confirmed when actual tubes with faceplates are interfaced to the eyepieces.

The physical lengths and weights of the final units delivered were greater than current standards prescribed for headworn goggle use. The 18mm units were 89.9mm in length and weighed 358.1 grams. The 25mm units were 110.2mm in length and weighed 390.2 grams.

In the final analysis, these two eyepiece designs confirmed the feasibility of a wide field of view cyclops configured eyepiece. The lengths and weights of the final units were not advantageous for headworn goggle systems, but are applicable to hand held night vision systems. Further improvements in the length and weight categories may be possible, but sacrifices would have

to be made in the areas of off-axis resolution, field overlap,  
and general system performance.

## 5.0

### THIRD GENERATION SYSTEMS (Contract DAAK70-77-C-0294)

This work involved the design and fabrication of optical subassemblies for use in prototype goggle systems having third generation image intensifier tubes. The contract specification was for quantity of two each of a 40° field of view, 12mm format objective lens, and a 40° field of view, 18mm format cyclops eyepiece.

Interfacing to third generation image intensifier tubes primarily affects the objective lens design. These intensifiers have a .22 inch thick, flat Corning 7056 glass faceplate with the photocathode material deposited on the inside surface. The faceplate then is a part of the objective lens optics as the image is on the inside surface. The photocathode material has more red response than the standard second generation intensifier requiring objective lens color correction over the range from 700 to 900nm. With the output phosphor material being the same P20-type as the second generation tubes, the eyepiece design criteria is unaffected by the tube type.

## 5.1 OPTICAL DESIGN

### 5.1.1 12mm Format Gen III Objective Lens

Baird's design goal for this lens was an f/1.2 lens in six elements. The final design consists of four singlets plus one doublet. Table 5-1 demonstrates that the characteristics of the final design exceed those specified. The T/no. shown for the final design is based on 99% transmission for ten air-to-glass surfaces.

		<u>Contract Specification</u>	<u>Baird Design</u>	
Format		12mm*	12mm	
Field of View		N.S.**	42.4°	
Effective Focal Length		18 ± 1mm	17.5mm	
Distortion		N.S.	10% barrel	
T/no.		T/1.6 or faster	T/1.34	
f/no.		f/1.4 or faster	f/1.28	
Length		N.S.	35.99mm (including face-plate)	
Weight		N.S.	12.73grams (less faceplate)	
Stray Light		<2.5%	<2.5%	
		<u>on-axis</u>	<u>14° radial</u>	
MTF-	10 lp/mm	86%	66%	} See Figures 5-3 and 5-4
	20	73%	32%	
	30	58%	15%	
	40	45%	8%	
Focus		25cm - infinity	25cm - infinity	
Optical Backfocus (infinity)		N.S.	7.10mm (including tube faceplate)	

\* Image plane on inside surface of flat .22 ± .010 inch thick Corning 7056 glass faceplate.

\*\* Not Specified

Table 5-1. Specifications and Design Results - 12mm Format Third Generation Objective Lens

During the design process, the most significant factors were the flat field and the thick faceplate. In general, the faceplate contributes over-corrected spherical and axial chromatic aberrations, as well as off-axis astigmatism and coma. Additionally, the effectiveness of a field flattening element close to the image is limited by the physical plate thickness.

Aberration fan plots for the final design are provided in Figure 5-2 with MTF plots for  $0^\circ$  and  $14^\circ$  field angles shown in Figures 5-3 and 5-4.

#### 5.1.1 18mm Format $40^\circ$ Field of View Cyclops Eyepiece

The lens design of this system is a derivative of the 12mm cyclops eyepiece design (Section 3.0). As the discussion of the wide angle cyclops eyepieces pointed out, a cyclops system can be modified to accommodate different formats by changing the collimator design only. To permit use of the plunging type of interpupillary adjustment, the 12mm cyclops focusing eyepiece/re-imaging lens designs were coupled with a new collimator designed for an 18mm format with the same field of view and output aperture as the original 12mm format collimator.

The aberrations of the new collimator (Figure 5-5), reflect the same levels of field curvature and astigmatism as exhibited in Figure 3-9 for the 12mm design. Note though, that the aberrations as a function of aperture are more linear, indicating that the final assembly will have less higher order aberration contributions from the collimator.



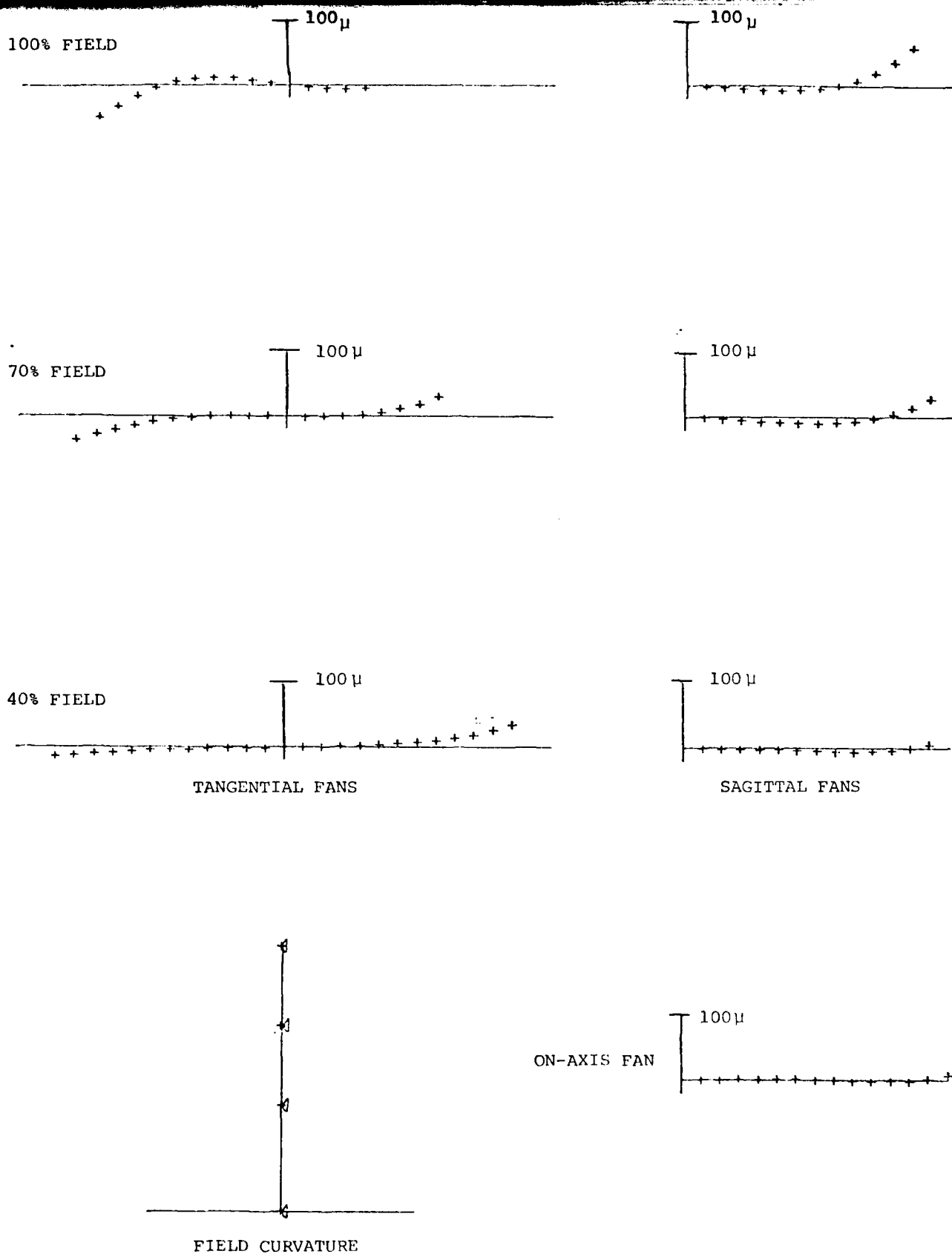
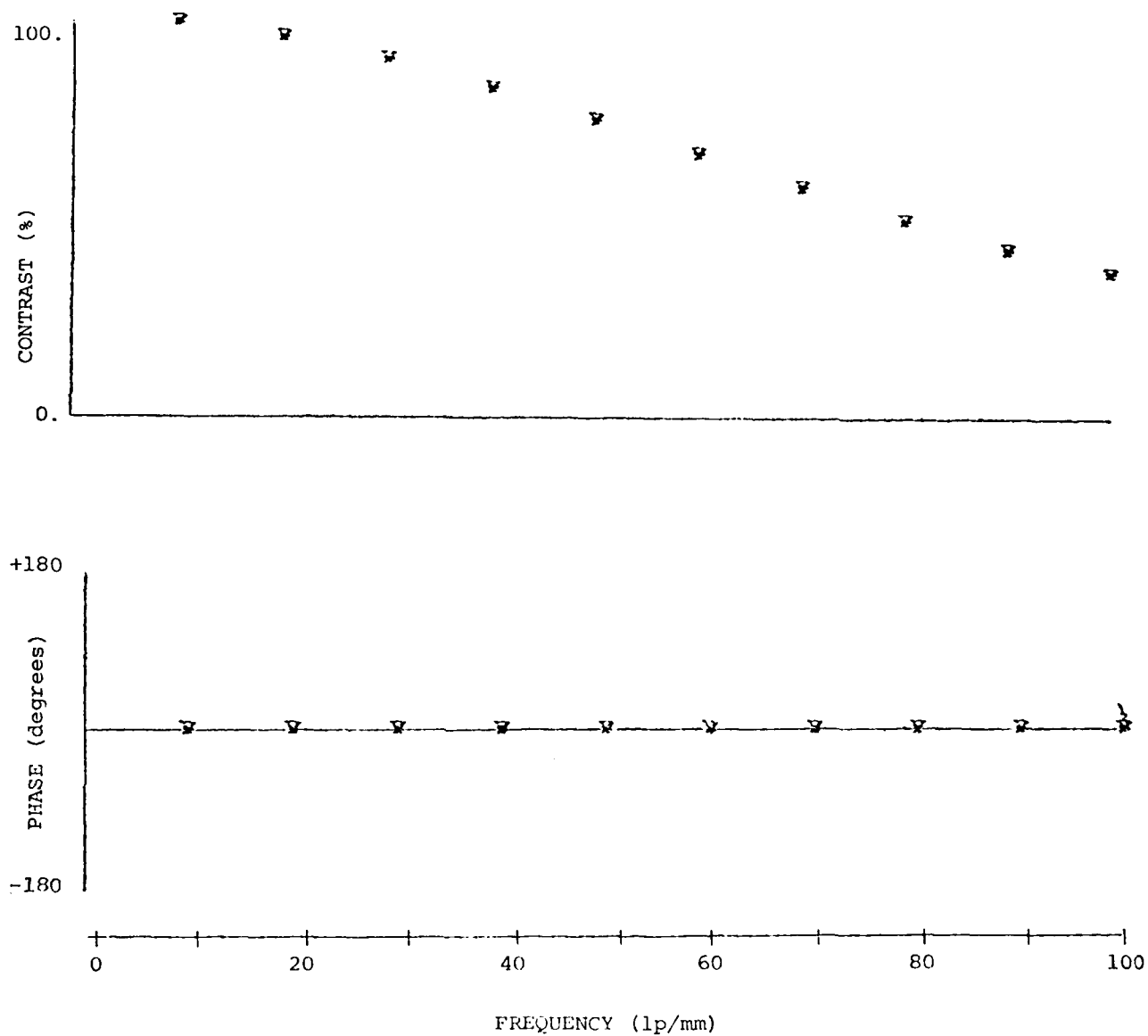
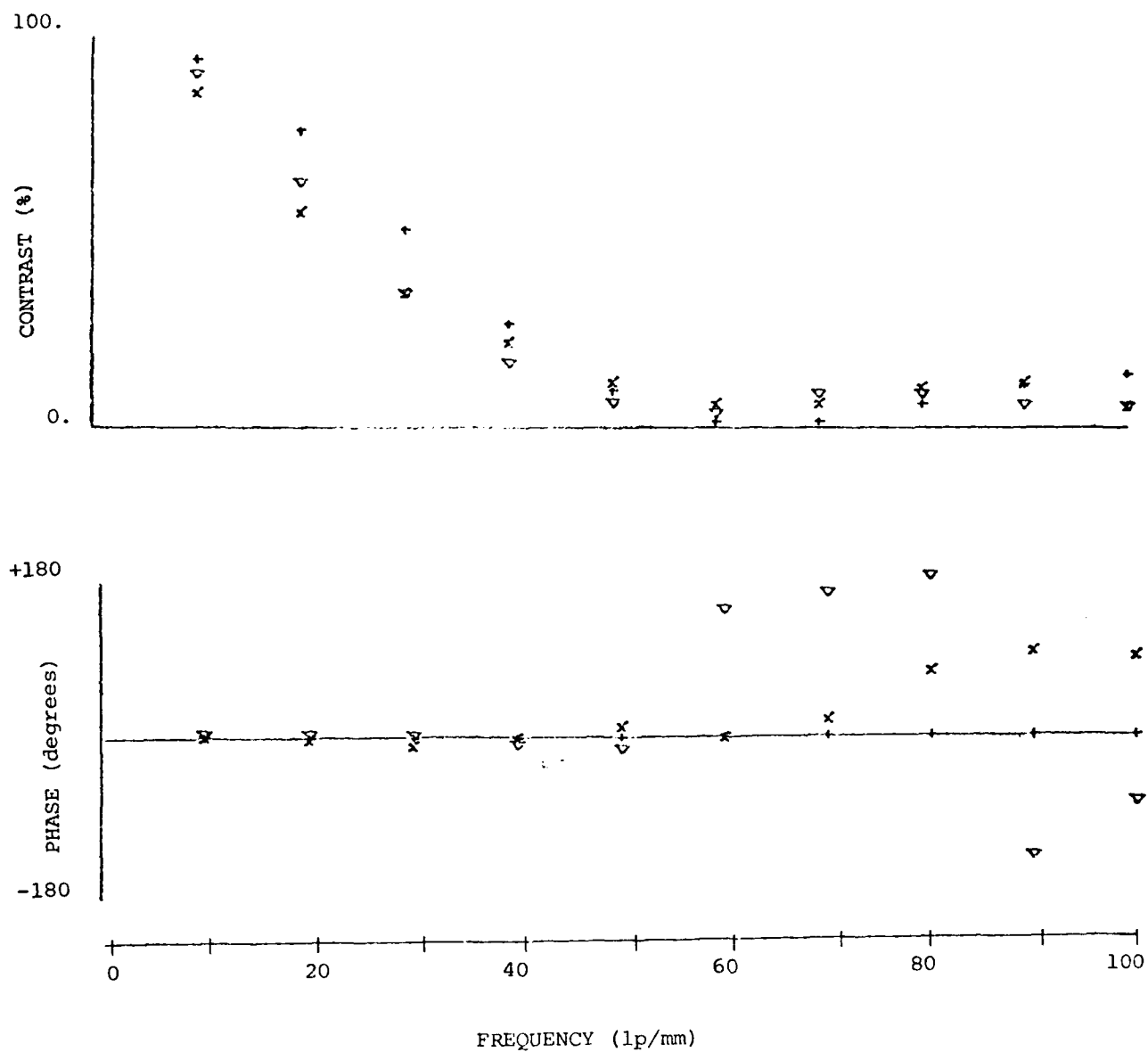


Figure 5-2. Aberration Fan Plots-12mm Format Third Generation Objective Lens



		WAVELENGTH (NM)	MTF WEIGHTING
x	TANGENTIAL	800	40
+	SAGITTAL	700	20
∇	45° RESPONSE	900	20

Figure 5-3. On-axis MTF - 12mm Format Third Generation Objective Lens



		WAVELENGTH (NM)	MTF WEIGHTING
x	TANGENTIAL	800	40
+	SAGITTAL	700	20
∇	45° RESPONSE	900	20

Figure 5-4. 14° Off-axis MTF - 12mm Format Third Generation Objective Lens

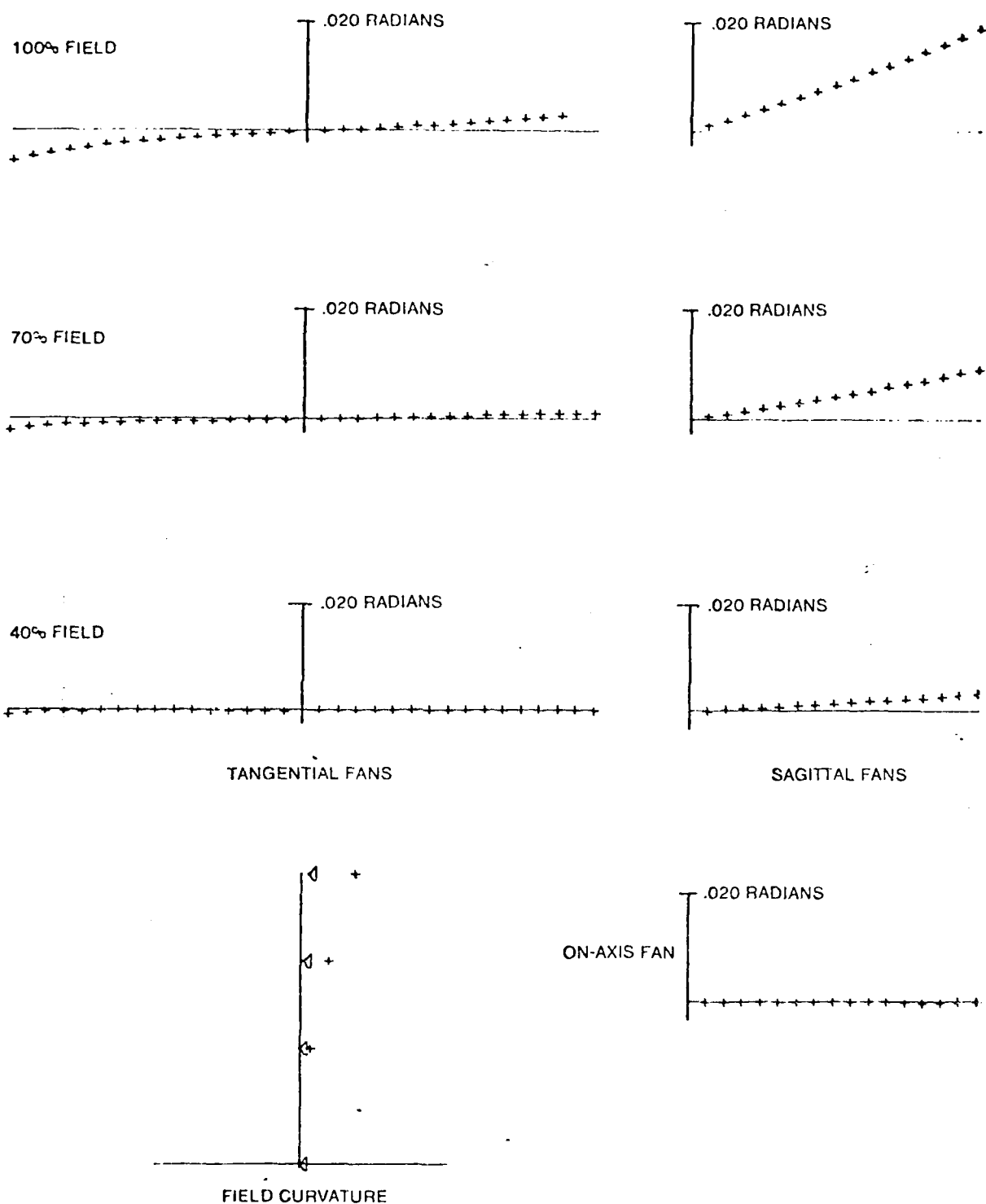


Figure 5-5. Aberration Fan Plots-18mm Format Collimator Third Generation Cyclops

Table 5-6 lists the contract specification and design results for the total eyepiece having the 18mm collimator coupled to the 12mm eyechannel.

### 5.3 MECHANICAL DESIGN

#### 5.3.1 12mm Format Gen III Objective Lens

The external dimensions of the objective lens assembly are given in Figure 5-7. The surfaces designated "mating surfaces" allow for the travel required to focus the lens from 25cm to infinity. These surfaces provide physical reference to the objective lens optical axis.

#### 5.3.2 18mm Format 40° Field of View Cyclops Eyepiece

The mechanical design of this system is a modification of the 12mm cyclops eyepiece (See Figure 3-12). The differences are greater collimator length, increased diameter of the collimator assembly near the intensifier tube output, and increased eyechannel travel (12mm system had 58mm minimum interpupillary spacing, while this system required 55mm).

The information for coupling the eyepiece system to an intensifier tube assembly is provided in Figure 5-8. The .942 inch dimension referenced in Note 1 is the collimator focus dimension. Datum A is the surface provided to center the collimator output on the intensifier tube output.

### 5.4 RESULTS

#### 5.4.1 12mm Format Gen III Objective Lens

Both units were examined and found to comply with the design. MTF measurements were made with an unfiltered light source implying some image degradation due to chromatic aberrations

from the light energy at wavelengths shorter than 700nm. Table 5-9 shows the  $0^\circ$  and  $14^\circ$  results obtained for one of the units. This data was taken with the lens focussed to optimize the  $14^\circ$  off-axis results. The second unit had similar MTF characteristics.

#### 5.4.2 18mm Format Cyclops Eyepiece

Both of the delivered units were examined for optical quality (via spot size versus field angle measurements), field of view, diopter range, and interpupillary range, and found to comply with the design.

Collimation was adjusted by the same method as described in the 12mm format cyclops section. Both of the delivered units measured  $.5^\circ$  collimation error maximum.

Picture quality was evaluated utilizing a fiber optic wafer with a polished plano input and a fine ground surface of 14.5mm spherical radius on the output. The full 18mm format was visible to each eye, with no merging problems. With a transparency mounted to the plano surface of the fiber optic wafer and back lit, the picture appeared to have adequate resolution over the entire field.

As was the case for the other cyclops eyepieces discussed, an energy fall-off was evident at the edges of the field. Manipulating the light source used for back illumination indicated that when the numerical aperture of the fibers of the wafer were completely filled by the light source, the brightness fall-off was not significant to each eye and less significant with both eyes viewing (due to the psychophysical integration of the two pictures seen by the individual eyes).

	<u>Contract Specification</u>	<u>Baird Design</u>
<u>Focusing Eyepiece</u>		
Focal Length	N.S.*	16.88mm
Field of View	N.S.	42.6°
Optical Backfocus (0-diopters)	N.S.	10.15mm
<u>Reimaging Lens</u>		
Focal Length	N.S.	17.17mm
Field of View	N.S.	42.6°
Optical Backfocus (0-diopters)	N.S.	13.25mm
<u>Collimating Lens</u>		
Focal Length	N.S.	27.90mm
Field of View	N.S.	42.6°
Optical Backfocus (0-diopters)	N.S.	5.08mm
<u>Total Eyepiece System</u>		
Format	18mm	18mm on (14.5mm radius of curvature)
Focal Length	27 $\pm$ 1mm	28.37mm
Field of View	N.S.	42.6°
Distortion	N.S.	-10% nominal
Pupil Diameter	N.S.	7mm
Eye Relief	N.S.	14mm
Overlap	100%	100%
Interpupillary Range	55 to 72mm	55 to 72mm
Eyepiece Focus Fange	+2 to -6 diopters	+2 to -6 diopters
<u>Collimation</u>		
Convergence	N.S.	$\pm$ 1° (goals)
Dipvergence	N.S.	$\pm$ .5° (goals)
Length	$\leq$ 3 inches	$\sim$ 3 inches including eye relief & backfocus
Weight	$\leq$ .75 lbs.	$\sim$ 4 lbs.

\* Not Specified

Table 5-6. Specifications and Design Results - 18mm Third Generation Cyclops Eyepiece

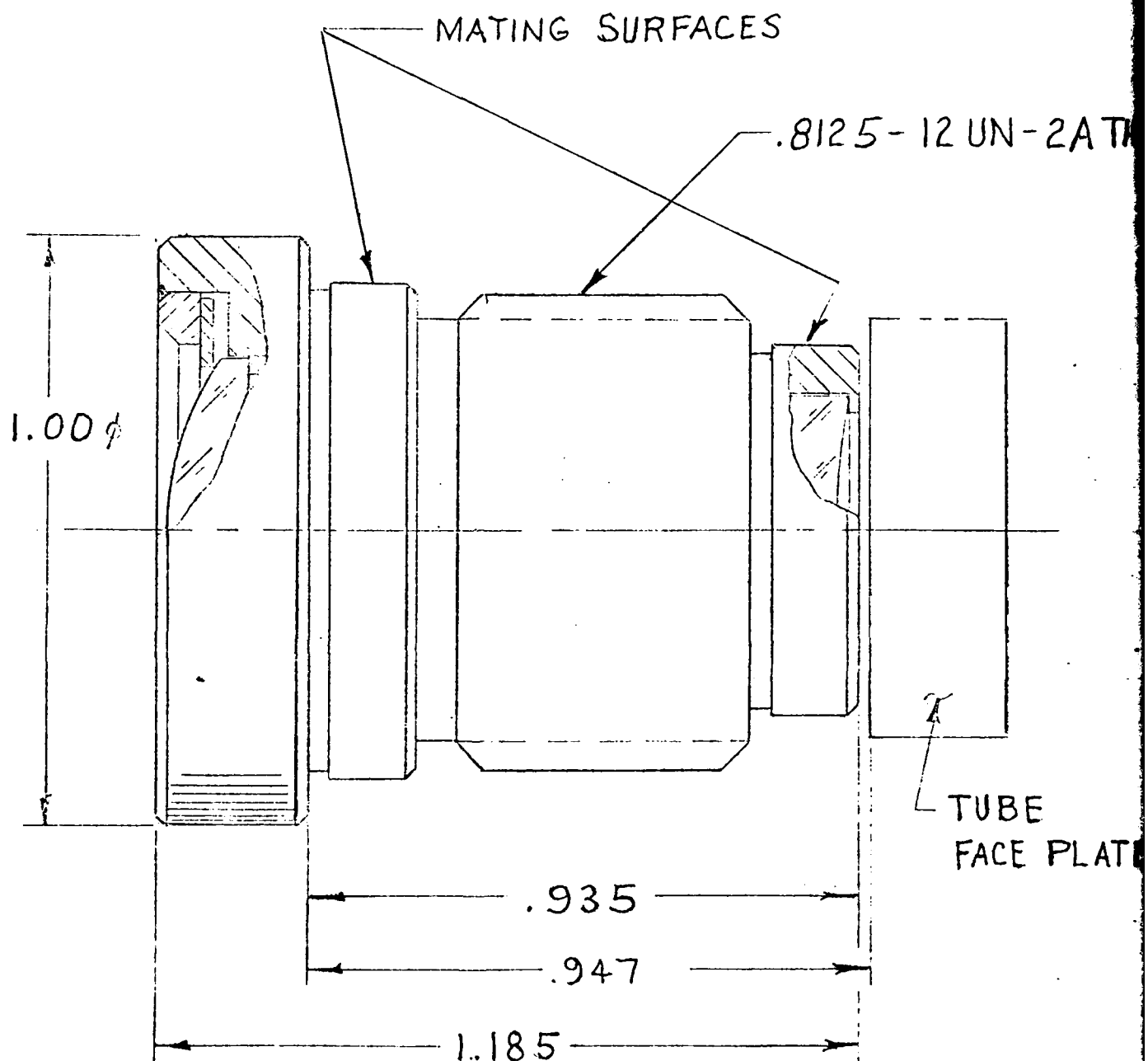
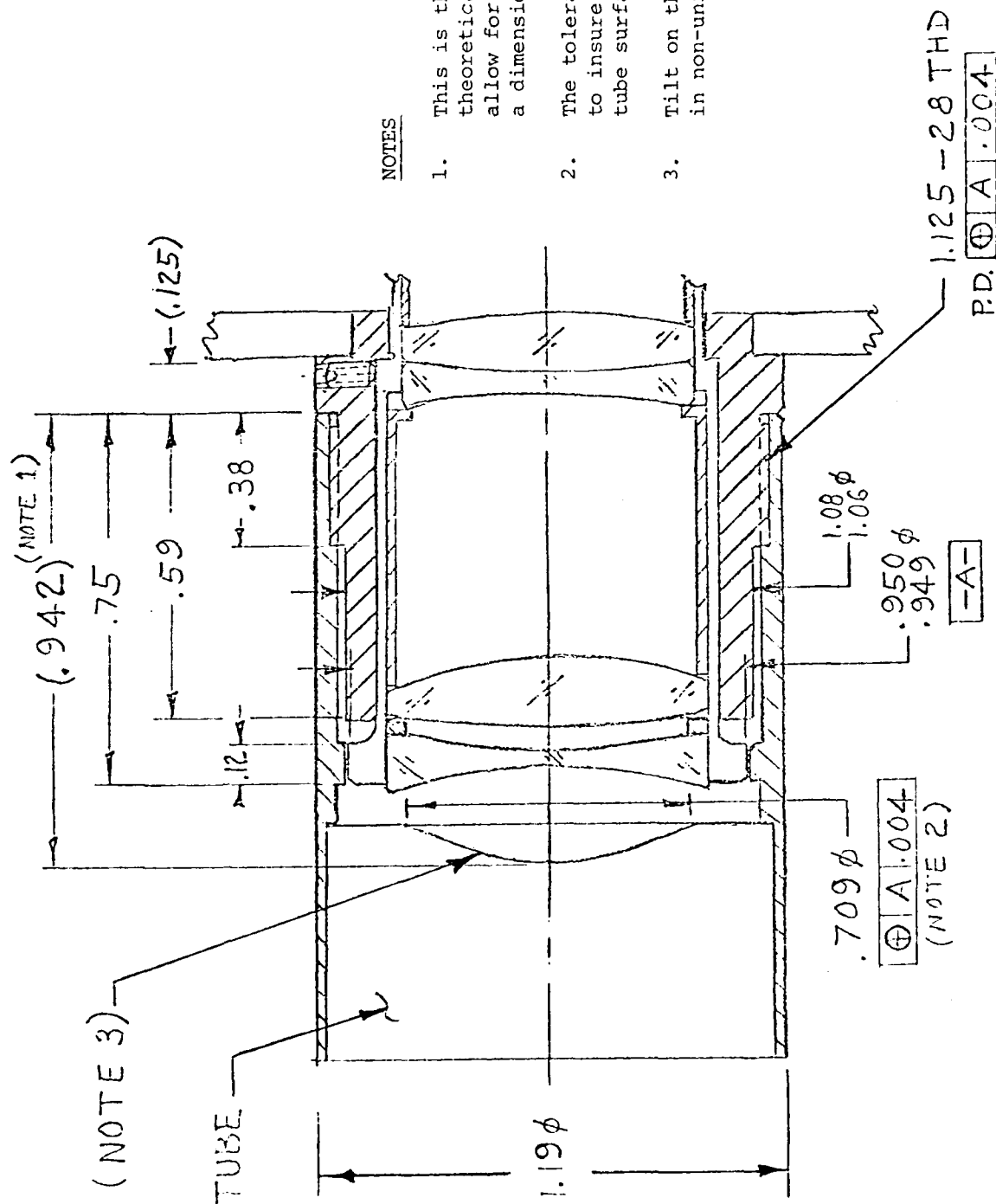


Figure 5-7. Interface Dimensions - 12mm Format Third Generation Objective Lens





# NOTES

1. This is the dimension to the theoretical backfocus. To allow for shimming at assembly, a dimension of .922 is recommended.
2. The tolerance given is required to insure centering of image tube surface.
3. Tilt on this surface will result in non-uniform image quality.

Figure 5-8. Interface Dimensions-18mm Third Generation Cyclops Eyepiece

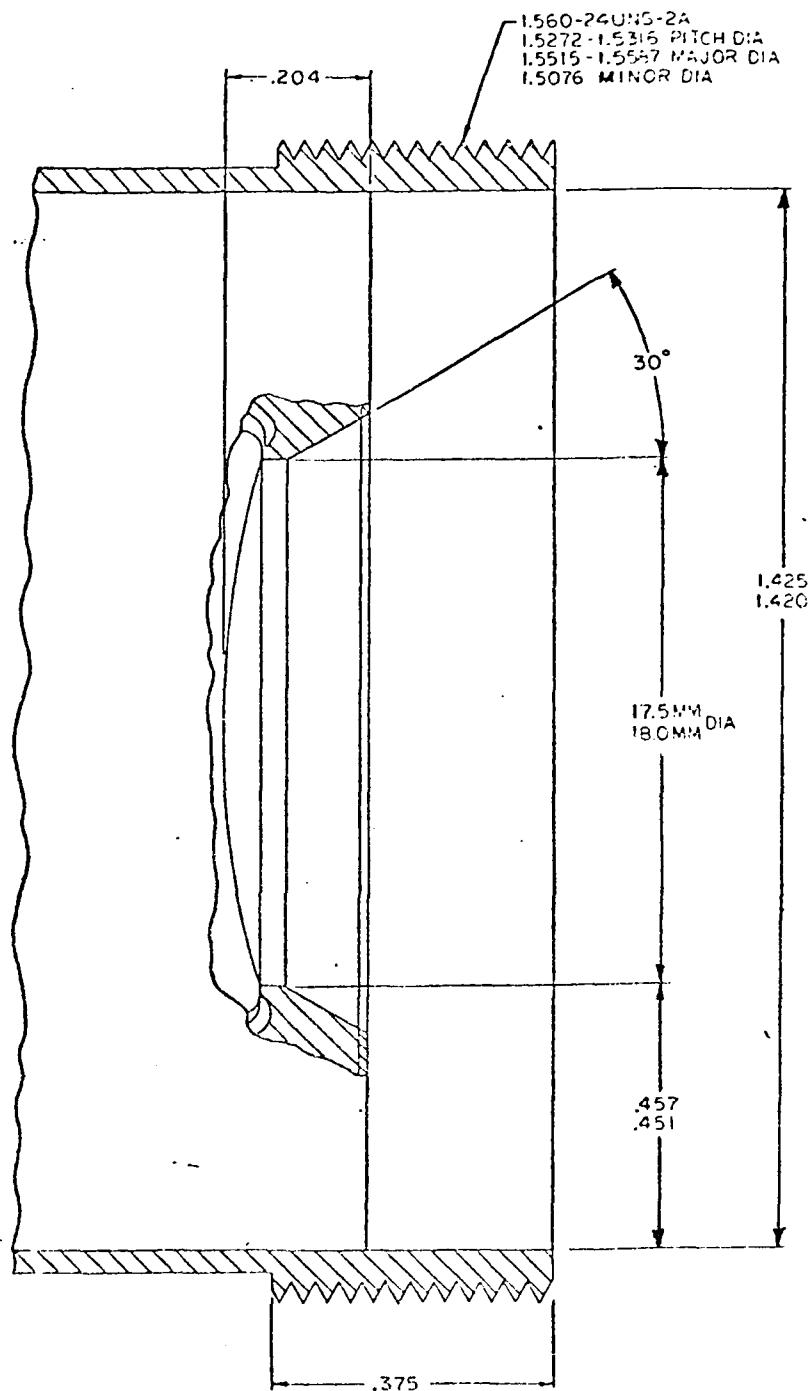
	<u>Frequency</u> <u>(lp/mm)</u>	<u>MTF (%)</u>	<u>Phase (°)</u>
<u>On-Axis</u>			
Tangential	10	93.7	0.0
	20	80.2	- 0.6
	30	62.2	- 0.4
	40	46.7	0.2
Sagittal	10	93.9	0.0
	20	80.1	- 0.9
	30	64.6	- 1.1
	40	49.9	- 3.9
<u>14° Off-Axis</u>			
Tangential	10	79.0	0.0
	20	48.1	1.4
	30	28.8	7.2
	40	18.4	5.4
Sagittal	10	91.9	0.0
	20	73.5	0.5
	30	49.4	- 0.6
	40	26.0	-14.9

Table 5-9. MTF Results for 12mm Format Gen III Objective Lens

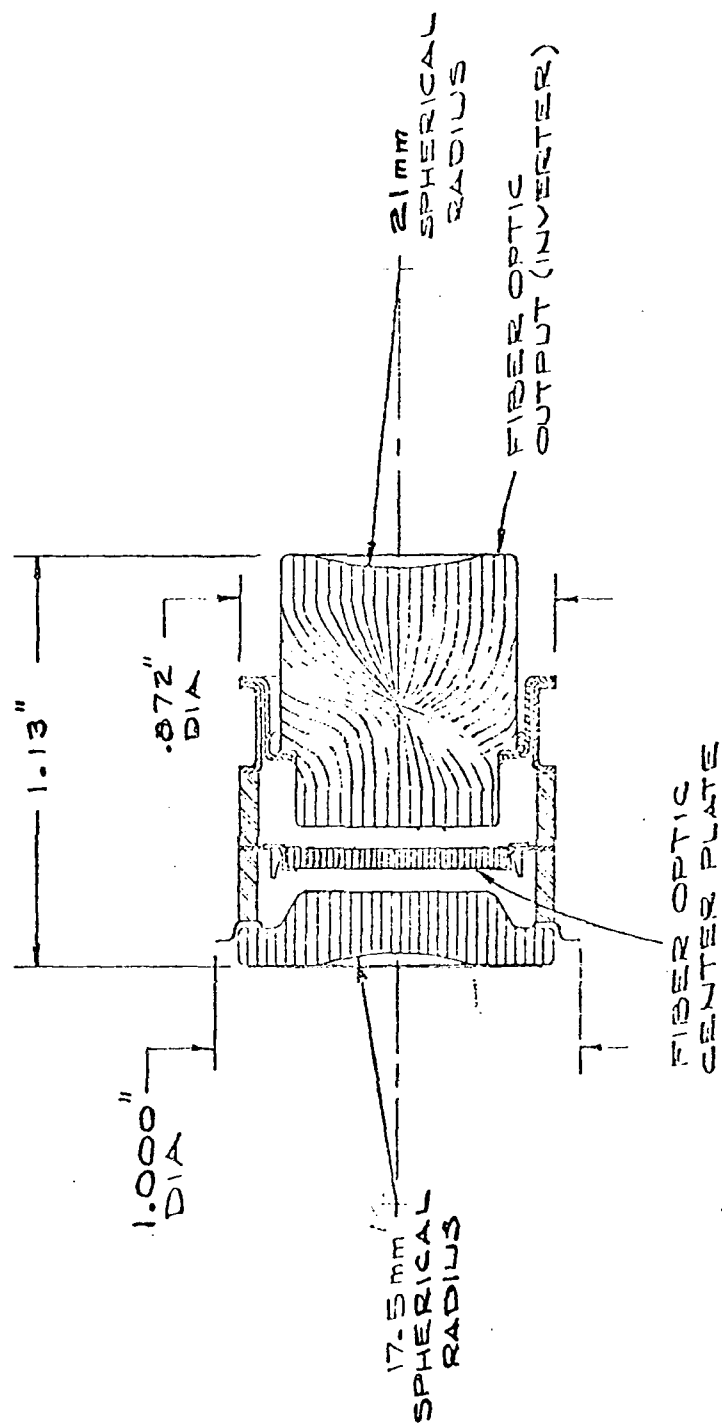
This 18mm format cyclops eyepiece was far superior to the original 18mm feasibility model (Section 2.0) both mechanically, and optically. This system was light, smaller, and mechanically more stable. The picture was of high resolution both on and off-axis and had better correction over the output pupil area.

Appendix A

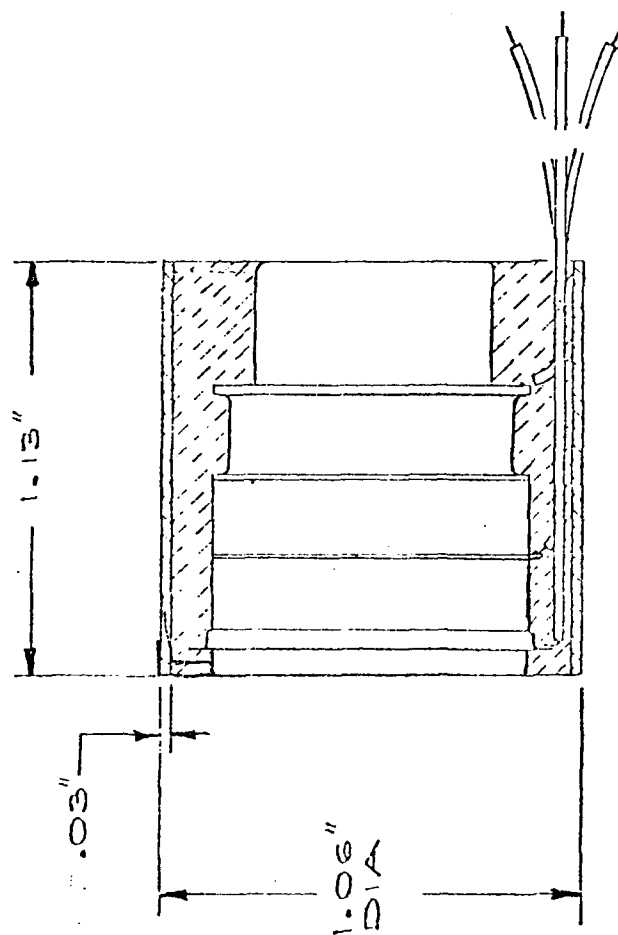
Drawings of Tubes Specified for  
Use with Prototype Systems



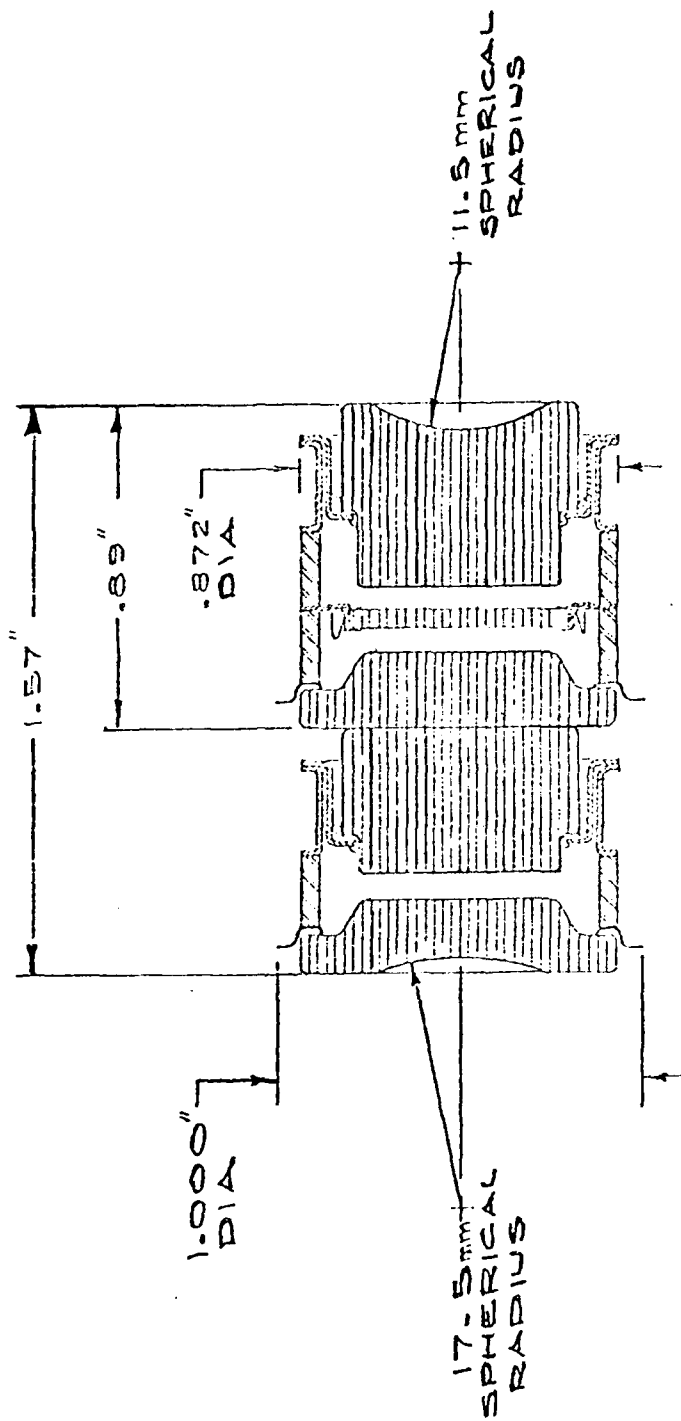
18mm Format Intensifier Tube Interface Specified for  
 Feasibility Model Cyclops Eyepiece.  
 (Contract DAAG53-78-C-0114)



12mm Format Double Diode Intensifier Tube Specified for Dual Channel 12mm Goggles. (Contract DAAK70-76-C-0254)

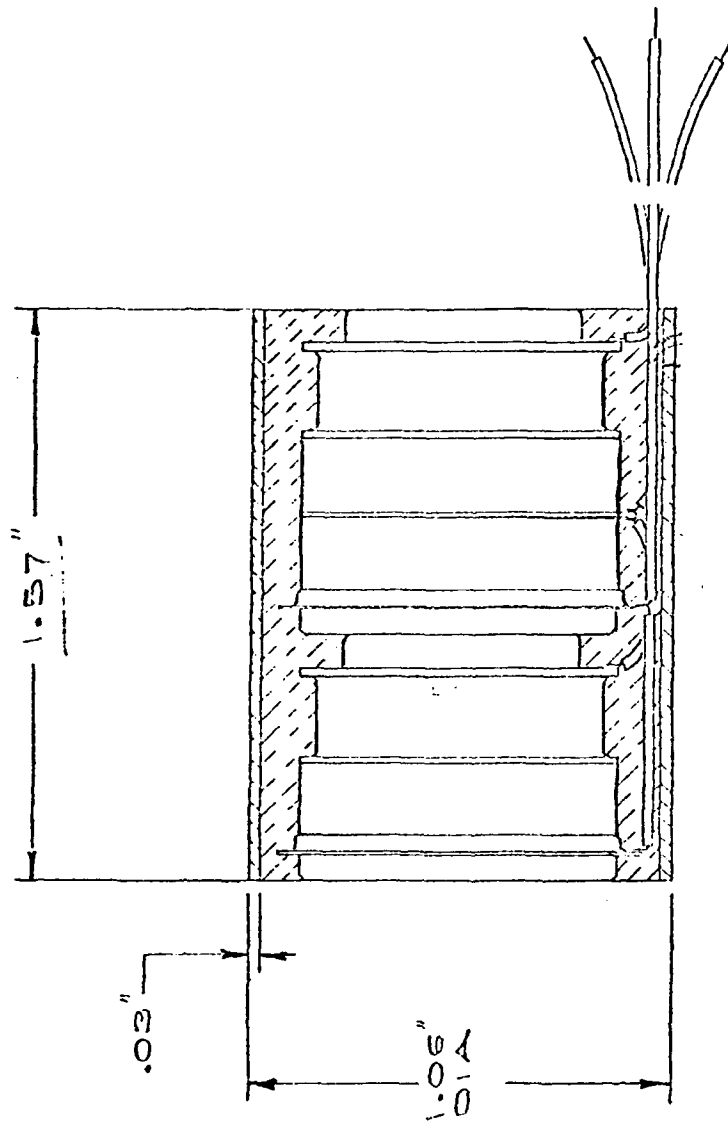


12mm Format Potted Double Diode Intensifier Tube Specified for Dual Channel  
12mm Goggles. (Contract DAAK70-76-C-0254)



12mm Format Triple Diode Image Intensifier Tube Specified for Cyclops 12mm Goggles  
(Contract DAAK70-76-C-0254)





12mm Format for Potted Triple Diode Image Intensifier Tube Specified for Cyclops 12mm Goggles. (Contract DAAK70-76-C-0254)

It can be concluded from the work documented in this report that two eye viewing of a single image intensifier is feasible. The different formats and configurations investigated lead to the following guidelines regarding the realizable capabilities of such an eyepiece system.

- 100% of the format may be viewed by each eye.
- 70 to 75% eyepiece transmission is possible.
- No severe design difficulties exist in attaining  $40^\circ$  field of view.
- Mechanical adjustment of interpupillary spacing can readily be achieved from 55 to 72mm.
- Closer spacings (less than 55mm) constrain lengths to the point of influencing the focal lengths, and apertures which may be used.
- Field angles greater than  $40^\circ$  are possible, but reflect increases in the physical size and weight of finished units.
- With proper aberration correction over the exit pupil area, pupil diameters as small as 7mm on-axis, vignetted to a cat's eye off-axis are adequate at 14mm eye relief.

Some particular applications which might prove to be informative are:

- Interfacing of the wide angle 18mm and 25mm format cyclops eyepieces to a front end consisting of either a 155mm format length AN/TVS-5 with 25mm tube or a 90mm focal length AN/PVS-4 with 25mm tube. The difference in cyclops format will result in changes in the apparent field of view and system power. In field situations, the two-eye viewing could prove preferable over the current monocular viewing for some applications.
- Interfacing the second generation 12mm cyclops system to standard second generation 18mm format tubes. In that, the future of 12mm tubes, if questionable, the reduced weight and length of the 12mm format design could be worthwhile if the system performance proves adequate.
- Combine the 12mm cyclops eyepiece and the 12mm format generation objective lens with one of the new 18mm format third generation tubes and examine the same possibilities as mentioned in the previous recommendation.

- With adequate correction of field curvature, astigmatism and differential distortion, picture quality equivalent to the standard AN/PVS-5 system is possible.
- Hinge interpupillary mechanisms involve greater difficulty when considering environmental sealing, whereas the sliding interpupillary mechanism offers a higher potential for sealing without complex structures.
- 40° field of view, 18mm format cyclops eyepieces can be made with glass elements having lengths  $\leq 3$  inches and weights  $\leq .5$  inches.

In the area of goggle objective lens design, this work demonstrated that:

- Curved input faceplates on the image intensifiers make high resolution, F/1. objective lenses possible with only six optical elements.
- Objective lenses designed for use with the flat, thick faceplate of third generation image intensifiers can achieve F/1.3 with adequate resolution and relative illuminance in six optical elements.

All the systems fabricated were untested by Baird in conjunction with actual image intensifier systems which is especially important to the cyclops eyepieces which depend heavily on the numerical aperture of the output faceplates of the attached tube. It is strongly recommended that all of the cyclops eyepieces be so tested.

Cyclops systems offer a high potential for unit cost savings in future night vision goggle systems by making single intensifier tube systems possible. In evaluating the full extent of the capabilities of this type of optical system, it should be noted that alignment, and interfacing are much more delicate than is the case for standard monocular magnifier eyepieces. In eventual production, this delicacy can be alleviated by proper system engineering, but care should be taken not to conclude that poor results during quasi-field tests are due wholly to the cyclops capability without investigating the possibility of improper interfacing.